University of Newcastle upon Tyne
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The Performance of Double Skin Facades in Office Building refurbishment in Hot Arid Areas

PhD Thesis
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Abstract

The façade's configuration in hot arid areas is predicted to be responsible for up to 40% of the building's cooling loads. The increasing reliance of public buildings in Cairo on air conditioning systems indicates the failing role of the building envelope to perform its function as a moderator leading to an alarming increase in electricity consumption. Office buildings in Cairo consume 5-7% of the total national energy consumption. The need to reduce energy consumption in this sector targets benefits of reductions of electricity bills to building owners as well as reducing CO_2 emissions from the built environment due to increasing electricity generation.

The lack of maintenance funds left the office building facades in a deteriorated state. This deterioration of image led to abandonment of buildings and loss of economic revenue. Double skin facades were investigated as a novel façade refurbishment option, targeting a multi criteria framework for façade refurbishment set in this thesis.

To achieve the aim of the thesis, different façade technologies were simulated using a dynamic software (APACHE v.4.3.1) to understand their thermal performance. Quantitative results of simulations were parametrically examined to identify benchmark options for façade refurbishment to reduce building total cooling loads. Simulations results indicated up to 40% reductions in total cooling loads if a double skin façade with an outer reflective surface is used.

Information generated from the simulation of single and double skin façade configurations were inducted into qualitative theories predicting human comfort aspects within the workplace. Three qualitative criteria underpinning the psychological comfort of occupants and its impact on productivity are set for balancing energy saving measures through façade refurbishment. These criteria are: the need for a view out, day light availability for non-task performances, and perceived control over the façade in work places.

Acknowledgement

It is interesting that these words appearing at the beginning are not written till the end. I felt the emotional difficulty of writing the acknowledgment that not only indicates the accomplishment but also a farewell to a piece of work that had occupied a considerable amount of my time and thoughts during the previous years. A PhD is said to be an individual piece of work! Academically maybe! but in my experience it could not have been achieved without a group of people providing an academic as well as an emotional web of support to whom *'thank you'* is but the simplest of words.

Special thanks and gratitude to my loving parents, Professor Ahmed Hamza and Professor Samia Galal, for long years of prayers, caring and support, for always endorsing me with the value of academic work, and for being a live example of the real meaning and effort needed to be successful.

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Chapter One: Introduction

Key Concepts

Chapter 1: Introduction

1.1 Introduction:

This thesis aims to investigate the thermal performance of double skin facades in a hot arid climate to reduce building energy consumption. The double skin façade configuration is intended as a façade refurbishment option to improve the quality of the existing deteriorated office building façade stock in Cairo. It is investigated within a framework of a refurbishment option that may be carried out while sustaining the building's occupancy and finally contributing to the occupants' psychological comfort.

Egypt is a developing country that invests heavily in erecting new electricity generating power plants to meet the rising demands in consumption. The built environment is a major end user of electricity. An opportunity lies in improving both awareness on the use of energy and actual energy reductions through improving the thermal performance of the built stock. Office buildings occupancy, with their 9-5 working hours, coincide with the warmest air temperatures and highest direct solar radiations on the building façade. To provide thermal comfort and increase productivity air conditioning systems are utilized. With air-conditioning systems depending on electricity, and wealthy employers affording to pay, this leads to office buildings being a major electricity consumer. In this context, the double skin facades are intended as an energy conscious façade refurbishment option that passively reduces environmental and climatic effects on the office occupants. Studies on the thermal and visual impacts of using double skin facades in moderate and cold climate are still in their infancy phase, with even less than a handful of publications on the double skin façade's performance in hot arid climates.

1.2 Research Design:

Research design is defined by (Philliber et al. 1980) as a *'blue print'* of research dealing with four main problems: what questions to study, what data are relevant, what data to collect, and how to analyze the results.

In this thesis the research design is divided into three main areas that form a conceptual, theoretical and operational framework. The conceptual framework is covered in this chapter; the theoretical framework is covered in chapter two to chapter five. The operational framework is covered from chapter six to chapter nine in this thesis (Figure 1).

The conceptual, theoretical and operational framework underpin the research process

The conceptual framework classifies:

1. Rationale
2. A study's question
3. It's propositions
4. Scope and limitations

The theoretical framework

1. The relation between the context of Cairo and energy consumption
2. Relation between façade configurations and energy consumption
3. Relation between occupants and facades

***The operational framework** (based on* (Yin 2003)):

1. Its unit (s) of analysis;
2. The logic linking the data to the propositions;
3. Criteria for judging quality of research design; relating to construct, Internal, external validity and reliability of data
4. The criteria for interpreting findings.
5. Interpreting findings
6. Induction into qualitative theories

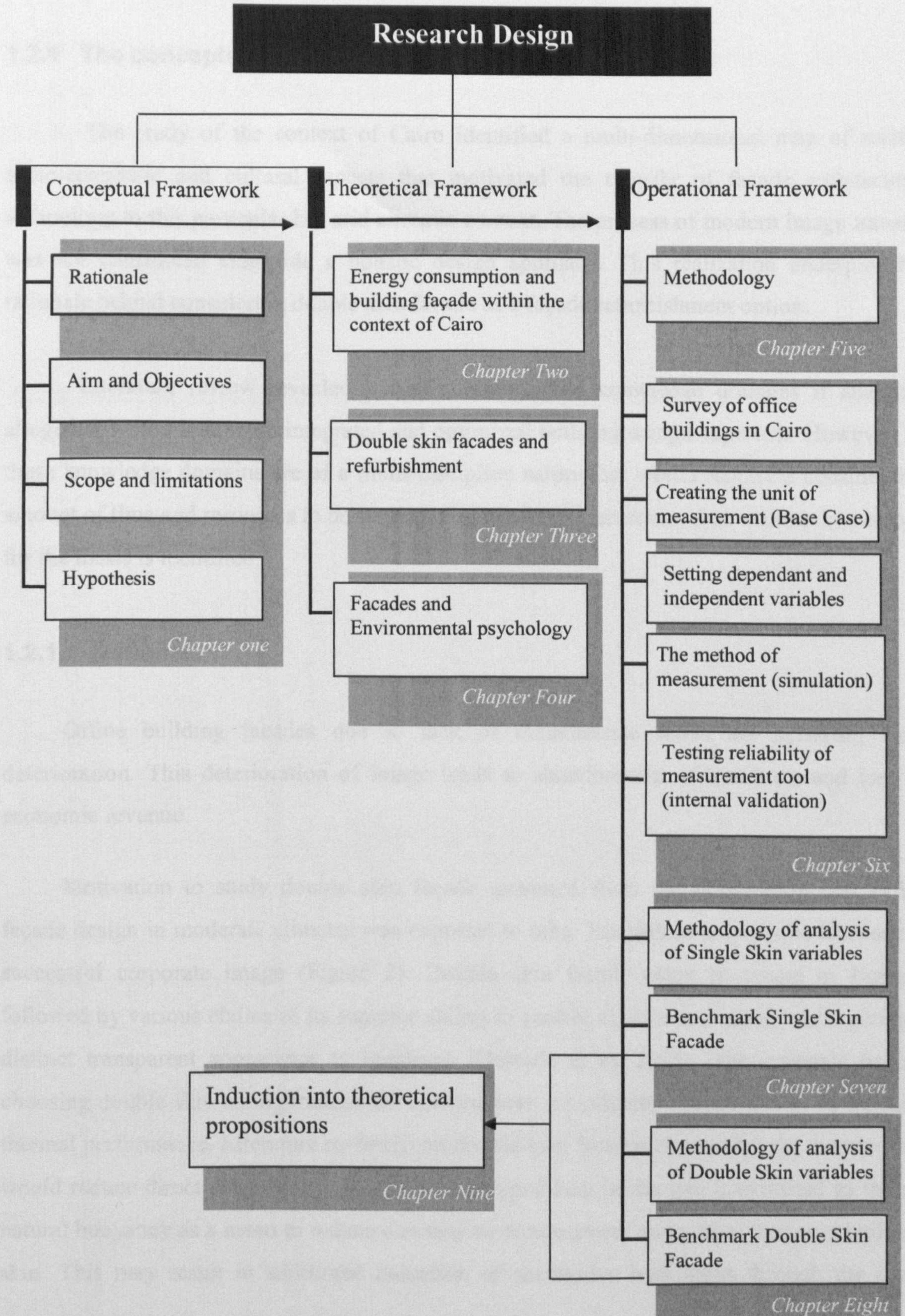


Figure 1: Research Design

1.2.1 The conceptual framework:

The study of the context of Cairo identified a multi-dimensional map of related socio-economic and cultural aspects that motivated the transfer of facade architectural technology to this particular hot arid climatic context. The process of modern image transfer was not considered alongside a holistic design approach. This realization underpins the rationale behind considering double skin façade as a façade refurbishment option.

Literature review revealed a map of interlinked knowledge domains if analyzed altogether would lead to an integrated and optimized building design approach. However, as these knowledge domains are of a multi-discipline nature that would require a considerable amount of time and resources to be studied simultaneously, an achievable -within time- scope for the thesis is identified.

1.2.1.1 Rationale:

Office building facades due to lack of maintenance funds are suffering from deterioration. This deterioration of image leads to abandonment of buildings and loss of economic revenue.

Motivation to study double skin façade stemmed from the observation that office façade design in moderate climates was exported to other location as a symbolic icon of the successful corporate image (Figure 2). Double skin façade came in vogue in Europe, followed by various claims of its superior ability to control climate and noise, while giving a distinct transparent appearance to buildings (Oesterle et al. 2001). The rationale behind choosing double skin configurations for construction in moderate climate lies in its inherent thermal performance. Literature reviewed on double skin facades claims that the exterior leaf would reduce direct solar heat gain in rooms; trapped heat in the gap is expected to induce natural buoyancy as a mean to reduce elevated air temperatures away from the inner building skin. This may result in additional reduction of conductive heat gains through the inner façade layers into the occupied space. The research intends to study the validity of these claims in a hot arid climate aiming to predict impacts of double skin façade on cooling loads in office buildings in Cairo. As an architectural concept, the external layer may be added to existing facades thus completing façade refurbishment work without the need to evacuate buildings. Evacuation of office building for refurbishment is a serious problem facing building owners when refurbishment is considered (discussed in Chapter Two).

The need to evaluate the performance of double skin facades stems from a scarcity of current research on its performance in a hot arid climate. It is not clear how this façade configuration can contribute to decreasing energy consumption in buildings while using environmental control systems to provide for human comfort indoors.

Figure 2: Image and facade technology transfer to Cairo

1.2.1.2 Aim

The aim of the research is to capture a balance between applying façade technologies and improving environmental psychological aspects in the office workplace while reducing energy consumption in a hot aid context.

1.2.1.3 Scope

To define the scope of this research an overview of the linked domains was identifies. The Venn diagram (Figure 3) highlights the various knowledge domains this research assumes is part and parcel of the final realization of a holistic building design whether in new construction or refurbishment. These variables were grouped into three major domains namely building visualization, building performance prediction and project management.

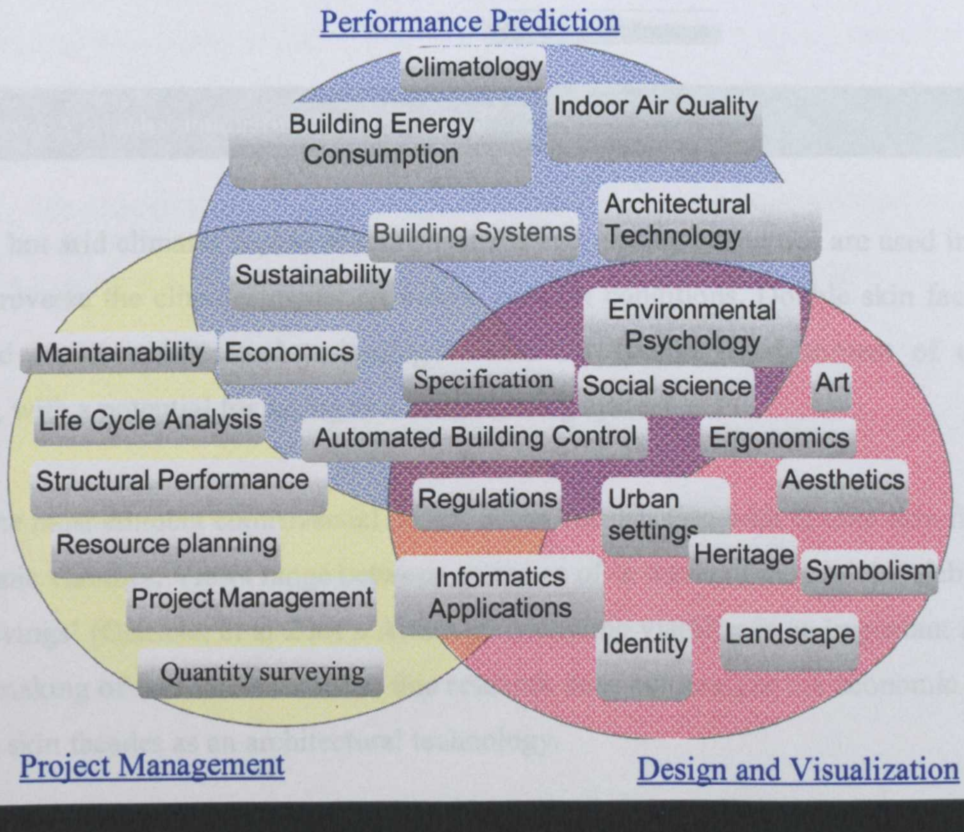


Figure 3: linked Knowledge domains towards holistic building realization.

It is evident that there is a large number of disciplines involved and due to the time limitation on this research a focused relation between the three variables of building technology, energy and environmental psychology are examined in detail in Figure 4.

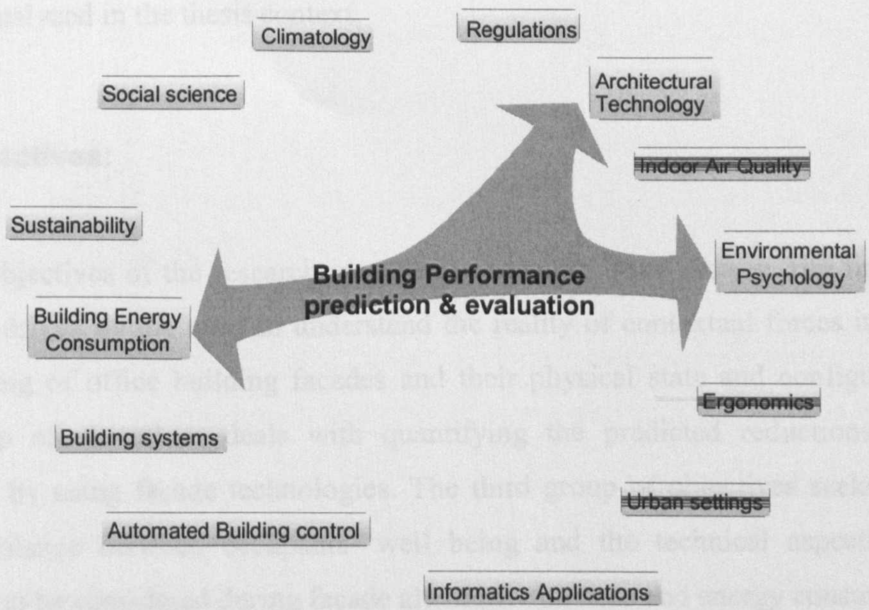


Figure 4: Variables dominating the thesis scope

In hot arid climates façade shading systems and glazing properties are used in various forms to reverse the climate impact on indoor comfort conditions. Double skin facades are introduced as an architectural technology viable for façade refurbishment of occupied buildings, with a potential for acting as a solar shading system.

The most eminent controversial debate about construction with double skin facades is its economic viability. Views range between extremes of 'a waste of money' to 'viable due to energy savings' (Ostriele, et al 2001). Although economic viability is an important aspect in decision making of façade alternatives, this research does not analyze the economic viability of double skin facades as an architectural technology.

Construction aspects of double skin façade are based upon highly detailed technological criteria. These criteria vary between fixation of elements to outer and inner facades, to inlet and outlet design and positioning, types and sizes of openings for natural ventilation and night purge, early fire detection system installation within the cavity, fire and sound propagation control within the cavity. These aspects although touched upon in the discussions underpinning the final conclusions are not part of the main body of building simulations analyzed in the thesis context.

1.2.1.4 Objectives:

The objectives of the research may be divided into three groups. The first group of objectives is driven by the need to understand the reality of contextual forces in Cairo that lead to shaping of office building facades and their physical state and configuration. The second group of objectives deals with quantifying the predicted reductions in energy consumption by using façade technologies. The third group of objectives seeks to find an acceptable balance between occupants' well being and the technical aspects of façade technologies to be considered during façade alternative choices and energy consumption.

1. First Group: To understand the context

a. To examine factors affecting design of office building façade in a particular context.

b. To explain factors necessitating refurbishment to the existing stock.

c. To examine the influence of climatic context on the façade.

d. To review factors affecting the well being of occupants' in relation to façade configurations.

2. Second Group: To understand relation between facades and energy consumption

a. To examine the energy impacts of using single skin façade technologies that may be used in existing facades' refurbishment.

b. To examine the energy impact of Multi-layered skin facades as an environmental mediator for refurbishing office buildings in a hot arid climatic context.

c. To compare an optimized single skin façade thermal performance to multiple skin façade alternatives.

3. Group three: To balance between reduction in energy consumption and occupants' comfort.

a. To explore the possibility of pursuing a holistic approach to office building façade refurbishment, in the sense of integrating the architectural expression with less energy consuming building services.

b. To examine the importance of reducing energy consumption balanced with aspects of environmental psychology of occupants affecting their productivity and sense of well being.

1.2.1.5 Limitations

The insufficiency of existing data on office buildings in Egypt is a major deterrent to understanding the energy requirements of buildings in different sectors. Although a few number of submitted thesis surveying different aspects of office buildings were found, a survey was needed for data gathering and field visits to office buildings in the existing stock were carried out to enhance understanding of the existing office building energy requirements.

Several variables were correlated to European and North American standards which in reality might be found to vary. Such as electric fittings consumption, space assigned for occupants, and occupation hours (discussed in Chapter Five and Six). However the rationale behind choosing European or North American values is that if buildings are to be refurbished, then more advanced systems for lighting, control and office equipments are used, which would then be comparable to foreign energy reduction requirements.

Official data available on office buildings in Egypt is scarce. The main source of data is based on the National Census of buildings (CAPMAS, 1998). Buildings are categorized either as residential or public sector buildings. Categories are defined according to the geographic location of each district, services provided, state of buildings, building height and extensions, and building materials. Extraction of the specific data was assessed to be an inaccurate process. Adding to the complexity was the fact that even the single table classifying the number of office buildings by height did not indicate whether these categories are based on number of floors in a purposed built office building or number of floors in mixed used buildings. Therefore site visits was required and existing literature on office building in Cairo was reviewed to ascertain observations.

No assessment of office building energy requirements was found in governmental publications and the only source available for information was compiled energy billing from office buildings received either by direct contact with building managers or by requesting information from the responsible in the Ministry of Electricity to supply data for a number of buildings. Another limitation of the data was that it is impossible to determine energy consumption by end use components (electric power used for computers, lighting, lifts or mechanical services) in buildings where occupants have changed electric circuiting.

1.2.1.6 Propositions:

Propositions in the thesis context are defined as the hypothesis of the study. Hypothesis according to Ragin are explained as *'an educated guess about what the investigator expect to find in a particular set of evidence. It is an 'educated guess' in the sense that it is based on the investigator's knowledge of the phenomena'* (Ragin, 1994:14). Nachmias (1992:61) extends the notion of defining hypothesis as a tentative answer to a research problem, expressed in the relation between independent and dependant variables where this relation is only verified by empirical testing. At the time of hypothesis formation the researcher does not know if it will be verified or not. (Nachmais and Nachmais 1992) adds *'hypothesis can be derived from theories, directly from observation, intuitively or in a combination of these approaches.'*

To assess the impact of refurbishing existing office buildings in Cairo with double skin façade configuration as opposed to refurbishment of single skin scenarios seven hypothesis are tested:

Hypothesis One: (operational alternative hypothesis)[1]

With no alterations to the architectural configurations reducing conductive gains through the façade configuration (transparent and opaque) will reduce cooling and heating loads.

Hypothesis Two: (operational alternative hypothesis)

With no alterations to the architectural configurations reducing radiation gains through the transparent façade area will reduce cooling and heating loads.

Hypothesis Three: (operational alternative hypothesis)

Major Alterations to the architectural façade configurations by reducing Window to Wall Ratios (WWR), and the Shading Coefficient (SC), will significantly decrease heating and cooling loads.

Hypothesis Four (Operational null hypothesis):

Compared to an optimized single skin façade, a transparent double skin façade may not achieve lower cooling load demands

[1] **Literary null hypothesis:** (concept oriented, no directional):
Ex. There is no relationship between support services and academic persistence of non-traditional aged college women.

Literary alternative Hypothesis: (concept oriented, directional)
Ex. The more that non-traditional aged college women use support services, the more they will persist academically.

Operational null hypothesis: (operational, no direction)
Ex. There is no relationship between the number of hours non-traditional aged college women use the student union and their persistence at the college after freshman year.

Operational alternative hypothesis: (operational, directional):
The more that non-traditional aged college women use the student union, the more they will persist at the college after their freshman's year

Hypothesis Five (operational alternative hypothesis):

Using a double skin façade configuration in a hot arid context with the exterior skin acting as a selective solar radiation barrier will reduce heating and cooling loads more than the Benchmark Single Skin façade configuration.

Hypothesis Six:

Applying a Benchmark Double Skin configuration on various existing office building façade configurations in Cairo will reduce building energy consumption.

1.2.1.7 Significance of the study:

Most of the available literature on thermal performance of double skin facades is carried out in moderate climate. Only one previous investigation was found to study the thermal performance of double skin facades in a hot arid climate in Arizona, USA (Afifi 1994). There are some evidence available from moderate climates on Double skin façade performance in extreme summer European days that was also reviewed in this study.

This study departs from previous attempts examining double skin facades:

- Deriving simulation variables from a specific built environment of Cairo, Egypt. Balancing results and recommendations to environmental psychology aspects of occupants in hot arid areas.
- This study links an architectural concept for refurbishment with regulations. As building thermal regulations are tightening in Egypt this façade concept reduces the thermal transmittance of walls to values quoted in the current regulations U_{opaque}=1.4W/m^2 K for external walls with windows.
- Previous research investigated the thermal performance of a double skin façade configuration in a hot arid climate within a different urban context and different attitude towards energy consumption in Arizona, USA (Afifi 1994). The previous research explored using shading materials into the cavity gap as the main control to reduce direct solar transmission into indoor spaces. Shading systems has proven to be effective in reducing direct solar transmittance when used on the exterior layer of single skin facades. In double

skin facades there is a debate on the economic dimension and feasibility of maintenance of using shading systems in the gap (Oesterle et al. 2001)This research looks at changing the visual properties of glazing of the double skin configuration with no dependence on shading systems in the gap.

- The analysis seeks to improve the thermal performance of a single skin Base Case, thus identify a benchmark single skin. The benchmark single skin is then compared to double skin façade scenarios to identify a benchmark double skin facade.
- Within the tested variables, both benchmark single and double skin are the most efficient façade configurations in reducing building cooling loads, the recommendation of their use is balanced by the need and constraints to provide an environmentally and psychologically comfortable environment.

1.2.2 The Theoretical framework:

The scope of the thesis identified, energy consumption, façade technologies, refurbishment and environmental psychology as the major domains of related interest to the inquiry However, literature review provided no single theory on the relation between these variables. The research literature review indicated singular approaches to identify the relation between façade configurations and energy consumption and on the other hand the relation between façade configurations and environmental psychology.

Previous research findings linking façade configurations to energy consumption perspective is reviewed in chapter (3&7) in this thesis. The classification of generated cooling/heating loads into envelope dominated loads and non-envelope dominated loads (Stein and Reinhold, 2000) is still open to debate depending on the specific morphology of the building and the distance between façade and occupants. An aspect that has been found to be linked to building regulations -with varying ranges- in general but not to single theory. Apart from specified U-values that were based on findings from scientific research, there is no single stated theory that would lead to recommending a certain façade configuration to a certain climate, but rather to a notion that every building facade is a peculiar case and has to be studied in its own climatic context.

Linking the environmental factors to human comfort in office buildings based on environmental psychology theories stated by Proshansky et al, (1976) relating all living organisms- including humans- to their environment: '*all living organisms engage in a complex interchange with their environments in the course of which they modify, and are modified by, what they encounter.*' A theory put in direct words by Winston Churchill: '*we shape our buildings then they shape us*'. The six major theories governing the domain of environmental psychology research leading to prediction of occupants' response to their environment are the theory of arousal, stimulus load, behavior constraint, adaptation level, environmental stress and ecological theories (Veitch and Arkkelin 1995). Due to human nature and the various influences on its reaction to its environment these theories are not treated as grand theories in research but rather as propositions. Although there seems to be a general consensus on what constitutes a good indoor environment considering adequate day lighting, electrical lighting levels and ventilation rates as stated in ASHRAE and CIBSE design guides, these variables always come with a clear warning that they are socio-cultural and economic dependant. This may explain the contrast in theories relating human performance to environmental conditions and difficulties in finding quantifiable results. This is attributed to the varying nature of human beings and non-environmental aspects that act upon their perception (state of mind) of comfort within a certain space and may affect their productivity levels (such as work-relationship, motivation and aspirations) (Bell et al. 2001). Productivity- measured by absenteeism rates and the number of mistakes in a certain task- has been the single quantifiable criteria to measure comfort in office spaces.

It is evident that each domain has its own theories but not in a single whole that could be used in this thesis for testing or comparing. However a triangulated approach to link theories is used in this context. Theories relating productivity in the workplace to environmental psychology concepts are linked to theories on the implications of façade architectural technologies on energy consumption.

1.3 Thesis Overview:

This chapter explains the conceptual model upon which the research is based. As outlined in (Figure 1), the conceptual model is based on explaining the motivation behind considering double skin facades for refurbishing Cairo's existing stock of office building facades. The aim, scope and limitations of research are discussed. The chapter ends by stating the hypothesis that underpins the structure and direction of analysis in both the conceptual and operational frameworks.

Chapter two focuses on understanding the context of Cairo as an urban environment influencing the construction modes of facades. This chapter also looks as modes of energy consumption in Egypt in general and in specific to office buildings. The reasons behind office buildings being a major energy consumer within the building environment are explained in relation to their environmental, urban, climatic as well as their occupancy patterns.

Chapter Three relates refurbishment as a sustainable option to maintain the functionality of the existing stock to double skin facades as an architectural technology. The methodology upon which a decision to refurbish a building is reached is discussed. The chapter then progresses with reviewing the Types of double skin facades. Precedents of the use of double skin facades as a refurbishment option are then reviewed as a platform for understanding the possibility of their use on existing buildings.

Chapter Four looks at the theoretical propositions underpinning the construction of facades and their impact on psychological comfort in the work place. Due to the context of Cairo's urban configuration and its climatic and environmental characteristics, this chapter looks at the wider context of requirements and expectations from a façade but focuses on the façade's role as a climate-environment moderator. It is argued that occupants' satisfaction with the façade underpins indoor comfort and affects productivity. In this context the impact of the façade on indoor configuration is discussed. This discussion feeds into the operational values chosen for the building simulation and finally on concluding on the façade refurbishment technology that balances both reductions in energy consumption while providing users comfort.

Chapter five briefly reviews research methodologies in relation to studying energy consumption within the built environment, and their evolution during the last thirty years. The chapter then explains an overview and discussion of the methodology of the operational framework of this thesis.

Chapter Six starts by the Cairo office building survey. The survey collected data on office building façade configurations and on electricity consumption bills. The chapter outlines limitations in data collections and the method of triangulation of data collection. The data gathered were analyzed. Results are used to construct the façade configuration of the Base Case (the unit of measurement), upon which façade variables identified in this chapter are to be tested and evaluated. Variables are divided into dependant and independent variables. Specific building modes of operation are grouped as dependant variables, while all façade technologies under investigation are grouped under the independent variables. To test the performance of different variables the different measurement methods are reviewed. The justification of choosing simulation as a measuring method to test the thesis hypotheses is illustrated. The general organization and model of the simulation is then briefly explained. Finally the chapter explains the method and results of testing the reliability of the software.

Chapter Seven presents the methodology for analyzing variables affecting the performance of the single skin façade to find a Benchmark Single Skin. This chapter explains in detail the simulation results in both tabular and graphical comparisons between the proposed refurbishment scenarios and the Base Case. A benchmark single skin façade utilizing the least cooling loads to provide indoor comfort is then used for further performance comparisons with Double skin façade scenarios. The chapter ends by testing the generalizability of the benchmark façade on other façade configurations identified from the office building survey.

Chapter Eight presents the methodology for analyzing variables affecting the performance of the double skin façade to find a Benchmark Double Skin façade. Similar to chapter seven, this chapter provides detailed simulation results in both tabular and graphical form for comparison between the different refurbishment options proposed, and the performance of the Base Case and the Benchmark Double Skin

The generalizability of Benchmark Double Skin Façade is tested on different façade configurations identified from the office building survey. The chapter ends by studying the daylight performance of the Base Case, the Benchmark Single Skin and the Benchmark Double Skin façade to test how these most energy efficient façade refurbishment scenarios will affect the amenity day lighting levels indoors as an important aspect of environmental psychology.

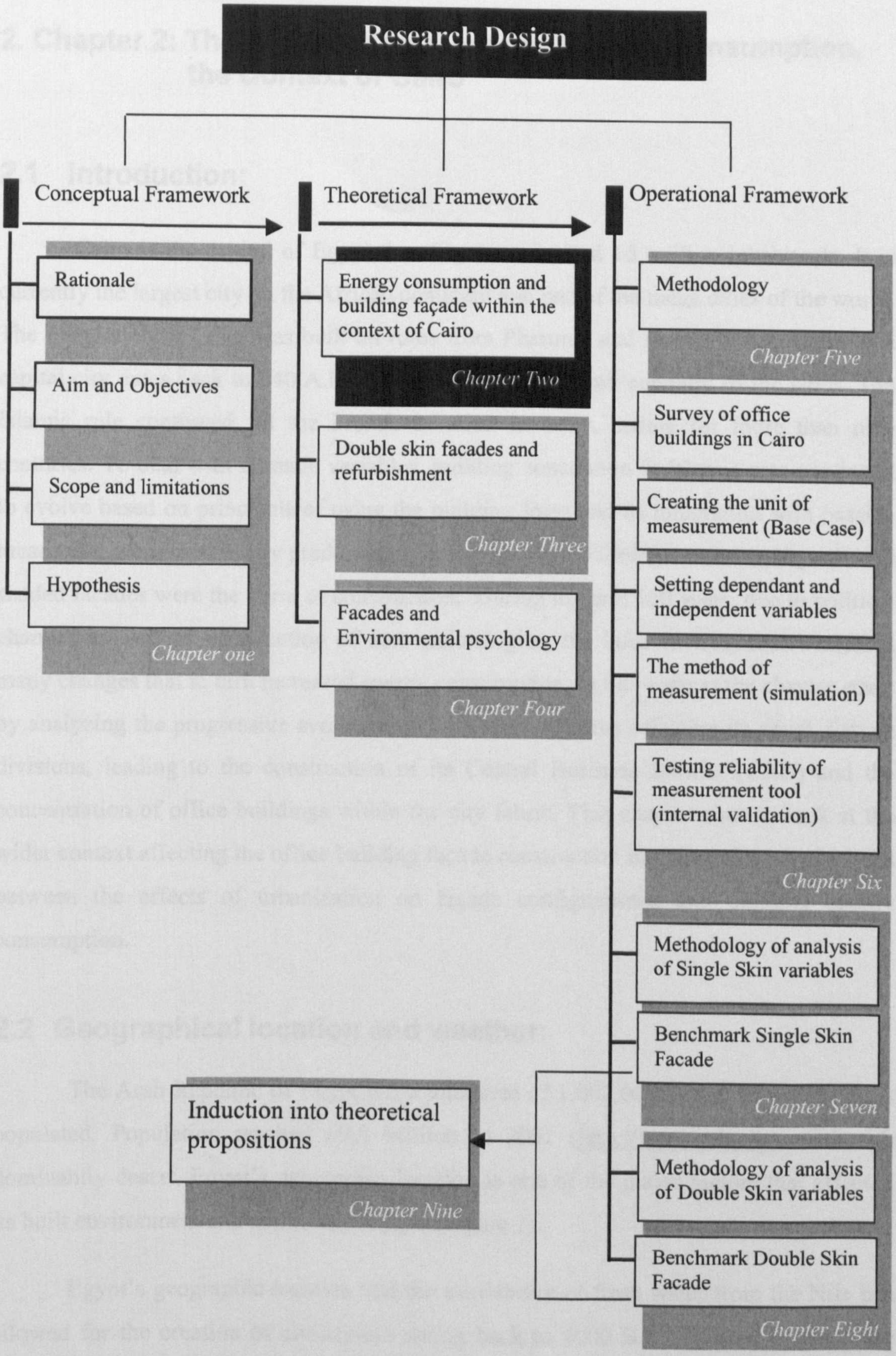
The conclusion chapter starts by discussing the performance evaluation tables, constructed to facilitate visualizing the results of each façade refurbishment scenario studied within this thesis. The chapter then links and balances the energy efficient façade refurbishment to the environmental psychological aspects of amenity daylight availability, the view out and perceived control.

Façade technologies are currently experiencing leaps in development to enhance their thermal and daylight performance. The incorporation of Photovoltaic cells, solar cells are but a few of the current research in increasing the building's envelope performance to not only reduce energy consumption but to generate part of the buildings electricity demand. These technologies will need to be investigated in future research to test their viability for a specific building's occupancy, climate and urban context.

Chapter Two: Cairo the Context

Key Concepts

2.1 Geographical location and weather
2.2 Historical Development of Cairo
2.3 Energy Consumption and the built Environment
2.4 Energy Use in Buildings
2.5 Expression of operational energy in façade aesthetics
2.6 Building Fabric and Service Integration



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Theoretical Framework
Operational Framework
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Double skin facades and refurbishment
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Chapter Five
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Setting dependant and independent variables
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Methodology of analysis of Single Skin variables
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Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
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Chapter Nine

2. Chapter 2: The Built Environment and Energy Consumption, the Context of Cairo

2.1 Introduction:

Cairo is the capital of Egypt, housing an estimated 16 million inhabitants. It is currently the largest city on the African continent and one of the mega cities of the world. The foundation of Cairo was built on ruins from Pharonic and Roman times. Cairo as a capital city dates back to 940 A.D. in line with the first Arab conquest of the lands. The Islamic rule continued till the French invasion in 1879, lasting for more than nine centuries. To deal with climatic variables, building conception in Islamic eras continued to evolve based on principals of using the building form and its integration with passive means that were historically predominant in Egypt. Thus building around courtyards and shaded facades were the norm of construction. During the past 150 years, due to political changes as well as introduction of new technologies, the built environment witnessed many changes that in turn increased energy consumption. In this context the chapter starts by analyzing the progressive evolution of the city and factors affecting its zonal distinct divisions, leading to the construction of its Central Business District (CBD) and the concentration of office buildings within the city fabric. This chapter aims to look at the wider context affecting the office building façade construction in Cairo, to study the links between the effects of urbanization on façade configurations and building energy consumption.

2.2 Geographical location and weather:

The Arab Republic of Egypt has a total area of 1,002,00 Sq. km, of which 5% is populated. Population reached 69.8 Million in 2001 (http://www.prb.org). Although dominantly desert, Egypt's geographic location is one of the major factors that affected its built environment and architectural style (Figure 1).

Egypt's geographic location and the availability of fresh water from the Nile has allowed for the creation of civilization dating back to 4000 B.C. Situated between the

Red Sea and the Mediterranean, Egypt has been a conquerors dream for controlling both Africa and the passage into the Asian continent. These conquests themselves had a far-reaching urban and environmental effect as they allowed for cultural interactions with the Middle East, Arabia as well as European and later American cultures.

These civilizations have mingled their own architectural styles with those predominant in Egypt (Ferguson, 1893, Roth 1993,Fletcher 1996, and Raymond 2001). This fertile land for architectural trials with their triumphs and faults had a pronounced effect on how buildings exert environmental control and on energy utilization in the building sector in the country, which will be discussed in this chapter.

On the other hand, the evolution of the city affected its transportation network and the availability of prestigious sites for office building construction. The transportation network and the planning of the city in their turn created an urban heat island and concentrated corridors of pollution all these factors affected not only building orientation but the façade's configurations. The following section looks at these impacts in more detail.

Figure 1: Egypt's geographic location

2.2.1 Cairo geographical location:

Egypt's capital city 'Cairo' is located on Latitude: 30° North and Longitude 31° East. Cairo with its situation on the river Nile, before it branches into the Delta, controls both access to Upper Egypt, the Delta and coastal areas. . The Geographic location had affected the growth pattern of the city and its transportation networks. Cairo did not evolve along a concentric pattern but followed a North - South axis of about 35km.in length following the path of the river Nile (Figure 4).

Natural geographic barriers to the city growth can be categorized into three categories:

The first barrier is the Nile and its hydrological profile. The Nile remained a historical natural barrier before the first bridge was built by Isma'il Pasha in 1872 followed by four bridge constructed between 1902- 1907. These bridges allowed for the flow of city expansion on the West banks of the Nile (the Gizah bank) (Figure 2) .Several bridges were built since then between Cairo and Gizah (Raymond 2001).

The changing hydrological profile of the Nile also affected city growth. The Nile course itself has shifted 300m to the west by the Fatmid Period, then 400mts by the Ayyubids and Mamluk, and more than 500m by the start of the 20^{th} century (refer to chronological order of dynasties and rules in Appendix one). This made available lands for further expansion of the city. However major parts of these strips were flooded during the inundation season and were not used for urban expansions until the construction on the Aswan Dam in 1902 (Raymond 2001:12).

Figure 2: The Nile as a natural barrier

The presence of the Nile affected the planning grid of the newly developed city centre. These plans have been drawn up by European planners that have applied the same guidelines for planning in Europe to Cairo's (Figure 6).To give buildings the privilege of the Nile view buildings were predominantly facing the East-West axis, which is known to be the worst climatic orientation for a building in a hot arid climate. It is noted that even the new developed transportation networks followed the same axis, thus not only the buildings facing the Nile but the plots behind them had the same orientation.

The second barrier is the agricultural land to the East and North of the city. This remained as a natural barrier till the end of 1930's. The city suddenly witnessed a demographic leap that is continuing till the present day. Cairo's Population growth followed the national pattern of growth rate at 4%. Coupled with increasing rural immigration, Cairo's share of the Egyptian population rose from 6% to 8% in 1937, 12.2% in 1947, 18.2% in 1976, to an estimated 22% in 2000 (http://www.alhokoma.gov.eg). Encroachment on agricultural lands raised concern of the government. As these areas were privately owned, the government had no legal control on their growth (Elkadi 1987). Transportation network were then created to encourage the extension of the city into the dessert.

The third barrier is the Mokattam and Tourah cliffs to the East of Cairo. Currently the road network has been able to extend past these barriers to the surrounding dessert, and the city is expanding rapidly in this direction.

Currently Cairo is divided into four overlapping main districts while satellite districts are in continuous growth around it.

2.2.1.1 Old Cairo:

These quarters includes Old Fustat and the Coptic Quarters and monuments. Cairo as it is known today owes it existence to the times of Arab conquer of the lands in 940A.D. *Kitab Futuh Misr wa Almagareb by Ibn al-Hakam* written two centuries after the invasion stated that by the time Arabs came, the location had only a stronghold of Babylon (a roman fortification) that housed a population of Copts and Jews. Amr ibn El-As was the first Arab leader to invade the land under the Caliph Omar instructions (640 A.D.). The rationale behind choosing the site for the new Muslim Capital (known as *Fustat* 'the tent') is attributed to Caliph orders to his army commander Amr ibn Al-As. The Caliph may have given Amr explicit orders: '*put no water between yourself and me, when I travel to you from Medina, my horse must take me directly to you*' (Raymond, 2001). However the process that gave birth to Cairo involved a series of foundations. Fustat established by the Arab conquerors (642 A.D); Al-Askar (750A.D.) and al-Qata'i (868A.D.) royal cities for the Abbasids and Tulunid. The parts of the city originated by Muslim leaders lay to the South of the current Cairo city and are only referred to as *'Old Cairo'*. The site is currently Cairo's landfill and waste collection area, efforts are currently being directed towards excavation of the city remains from the Islamic conquest era (Figure 4).

2.2.1.2 Islamic Cairo:

Constructed by the Muslim Fatmid leader Jawhar under Caliph Al-Mu'izz. The Fatmid's were a faction of Muslims known as *Shi'at*. They grew in number in Tunisia and Morocco. Jawhar conquered Egypt in (970 A.D.) and promised tolerance to the

Muslim *Sini* and the minority of Jews and Christians. Under the Caliph instructions a city to rule the world was to be built. In choosing the location for the new city Jawhar had three choices: to follow the Tulunid example and remain at a distance from the river; or stay near the Nile for it provided water; or move South again towards Fustat. Finally he chose a sandy plain north of the Tulunid city bounded on the East by Muqattam hills. There were no buildings expect a Christian monastery. Thus El-Qahira was constructed away from Fustat and the other earlier settlements to house the elite and ruler quarters. Surrounded by a fragile fence that disappeared by 1050 A.D. (Raymond, 2001). Soldiers' quarters and slaves (*abeed*) were housed out of these gates between the two cities. This development was to the north of the previous Islamic settlements. It continued to grow accommodating the growing city during Mamluk till Ottoman rule extending till the riverbanks (Figure 4).

Napoleon expedition in 1798 was marked as a major cultural turning point in the Egyptian history. It lasted only for three years after which Egypt's rule returned to the Ottman's who in 1804, accredited the hereditary rule of Mohammed Ali and his dynasty over Egypt. During Muhammed Ali's reign, Alexandria was to be the Capital and centre of trade and a link to the Western world. But the period between the start of the French invasion till the accession of Isma'il pasha in 1863 marks only the seed of what would become Modern Cairo.

2.2.1.3 Modern Cairo (Central Cairo):

The year 1863 marks the accession of Isma'il Pasha who launched a campaign to modernize Egypt. Cairo was to become his capital and showcase of the countries progress. Ismai'il was the first ruler in nine centuries to make an overall plan for Cairo's development. The recession of the Nile water and the narrowing down of its Eastward branch created a new stretch of land that was eagerly claimed for construction of modern Cairo districts. Modern Cairo or Central Cairo is therefore bordered by Old Cairo to the south, Islamic Cairo to the East and the Nile River to the west. These quarters (Namely Bulaq, Garden City, Rhoda Island) were constructed by the Mohammed Ali's Dynasty, to accommodate the royal family and the higher society. Hausmann was involved in the planning of these new quarters. After the British Occupation started in 1882, the trend of creating two different cities side by side intensified. It was not to mark the difference between the 'old' and 'modern' Cairo, but was a marked boundary between two nationalities. The old Islamic quarters for the 'natives', while the modern quarters for Elite ruling class and Europeans. The older quarters were neglected, with increasingly dilapidating services for cleaning and water supply, and further exacerbated by the rapid increase in its population to more than 120% between 1882-1927 (Farhi et al. 1972) (Figure 4).

2.2.1.4 The 'Free Soldiers Revolution' 1952:

Different architectural styles could be marked in accordance with the political leaders of the country naming Gamal Abdel Nasser and Anwar el-Sadat. The expansions of the city on the Western Nile shores (Giza districts of Mohandiseen, Agouza and Doqqi) were developed as middle class residential areas mostly during the 1960's and 70's to support the new Egyptian professionals class. Central Cairo accommodates the bulk of purpose constructed office space.

Gamal Abdel Nasser's Era (1952-1970); during this era most of the constructed office space was for governmental usage. Office space was generally provided as converted from residential use. Insurance companies were given the authority to manage and run the industry as well as residential buildings, and the converted to office spaces of Cairo's buildings that were nationalized from foreign owners. This Era also marks the rapid growth in informal settlements around Cairo that continues to the present day. (Imbaba, Warak, Bulak el Dakrur, some areas in Shubra, etc.). These areas cover now 27% of Cairo (Elkadi, 1987), and though a major planning and social concern is not the focus of this study.

Anwar El-Sadat Era (1970-1981); The decade between 1970 and 1980 was noticeable for two major political decisions that affected Cairo's urban environment;

First, the construction of several bridges between both banks of the Nile that would facilitate urban growth on the west bank on districts that were reserved for the elite in previous eras. The nearness of these districts to the old CBD on the Eastern Nile shore led to a "wild" service activity centre in Mohandessen and increasingly dense population on the West bank , which led to random destruction of the affluent villas that had been responsible for the architectural style of these districts.

Second, opening up the Egyptian market's to American and European market's known as 'open door policy' or '*Infitah*'. This policy led to many foreign companies operating in the country, importing their architectural ideas and materials to construct their own office space. The trend to demolish the elite districts such as 'Garden city' with their palaces and villas still continued. In their place high-rise concrete buildings appeared. Therefore, it is observed that the sleek office building facades of Cairo mostly appear in this era.

Cairo has been a highly centralized town. The 1972 and 1982 master plan recommended a multi-polar urban area via the creation and development of several secondary centers. In effect, CBD continued expanding mostly on the West bank of the Nile (Mohandessen and Zamalek).s The Originally Designed CBD during the Khedives reign (Planned by Hausmann), have been left to deteriorate. Laws freezing rental value, issued in 1961 (and repealed since that date), aimed to limit the concentration of service activities in the town centre, and encourage it in New designated Suburban areas. But this intention failed and as a result, services activities developed along its perimeter. Nowadays, the new definition of CBD tends to include the old CBD, the river island of Zamalek and the Western Nile shore of (Mohandessen, Dokki and Agoza).

2.2.1.5 Sub-Urban Cairo:

The first large scale town planning operation for a suburban district in Cairo goes back to the early Nineteen Hundreds and was initiated by Baron Empain. That was Heliopolis which was created in 1906 on a semi-desert area 10 km away from Cairo's city centre. The districts of Shoubra and Rod el Farag to the North of CBD also owe their development to the new tramway lines opened in 1902 and 1905. Later on, other tramway lines were built and extended (Pyramid Avenue to Gizah). The first master plan was prepared in 1953, and included in particular the new districts of Nasr City, Al Salam and Mokkatam to the NorthEast and to the South of Heliopolis, respectively.

The geography of the city affected the layering of its history and allocation of services. It is evident that public services, governmental and office space would be conglomerated in the best-serviced areas of the city. Apart from change of use from residential to work places, the Modern Quarters of Cairo (CBD), and on the main access routes to Heliopolis and Nasr city (Figure 3) witness the bulk of construction of these modern buildings to serve daily life requirements of the population. (Figure 9), indicates the concentration of the work forces in Cairo.


Figure 3: Dense urbanization in Nasr City

2.2.1.6 The effective development of Cairo between 1970 and 2000

The trends of managing the urban expansions of Cairo may be translated in (Figure 5).

- A reinforcement of the central area and the overflowing of CBD to the West bank of the Nile (Mohandesseen, Dokki), together with the abandonment of the project to build a major services centre to the East of Cairo;

- A continued uncontrolled expansion of lower class housing along the edges of urban or wealthy districts;
- Increased density of Cairo along the corridor of the first metro line to the East. (43 km long),
- Migration of the wealthier classes who leave the centre of town (flats being transformed into offices) for good quality developed districts (Nasr City, 15th Of May, and Mokkatam.),
- The belated launching of new towns (New Cairo, extension of 15th of May, Al-Sheik Zayed, 6th de October, Al Shorouk) which currently house circa 250,000 inhabitants as opposed to the 2.8 million initially forecast. Given the absence of rapid and affordable public transport (train) these new towns are populated by fairly wealthy social classes with cars.

Old Cairo (Coptic Quarters)

Fustat

Fatmid Cairo 970 A.D.(Al-Qahira)

Mamluk Ottoman Cairo

Mohammed Ali and his Dynasty period.

After the revolution, heavy urbanisation areas

Hydrological profile of the Nile in 970 A.D.

Mamluk- Ottoman Cairo

Elite districts during Mohammed Ali and his Dynasty

Figure 4: Cairo's Districts Historical Evolution

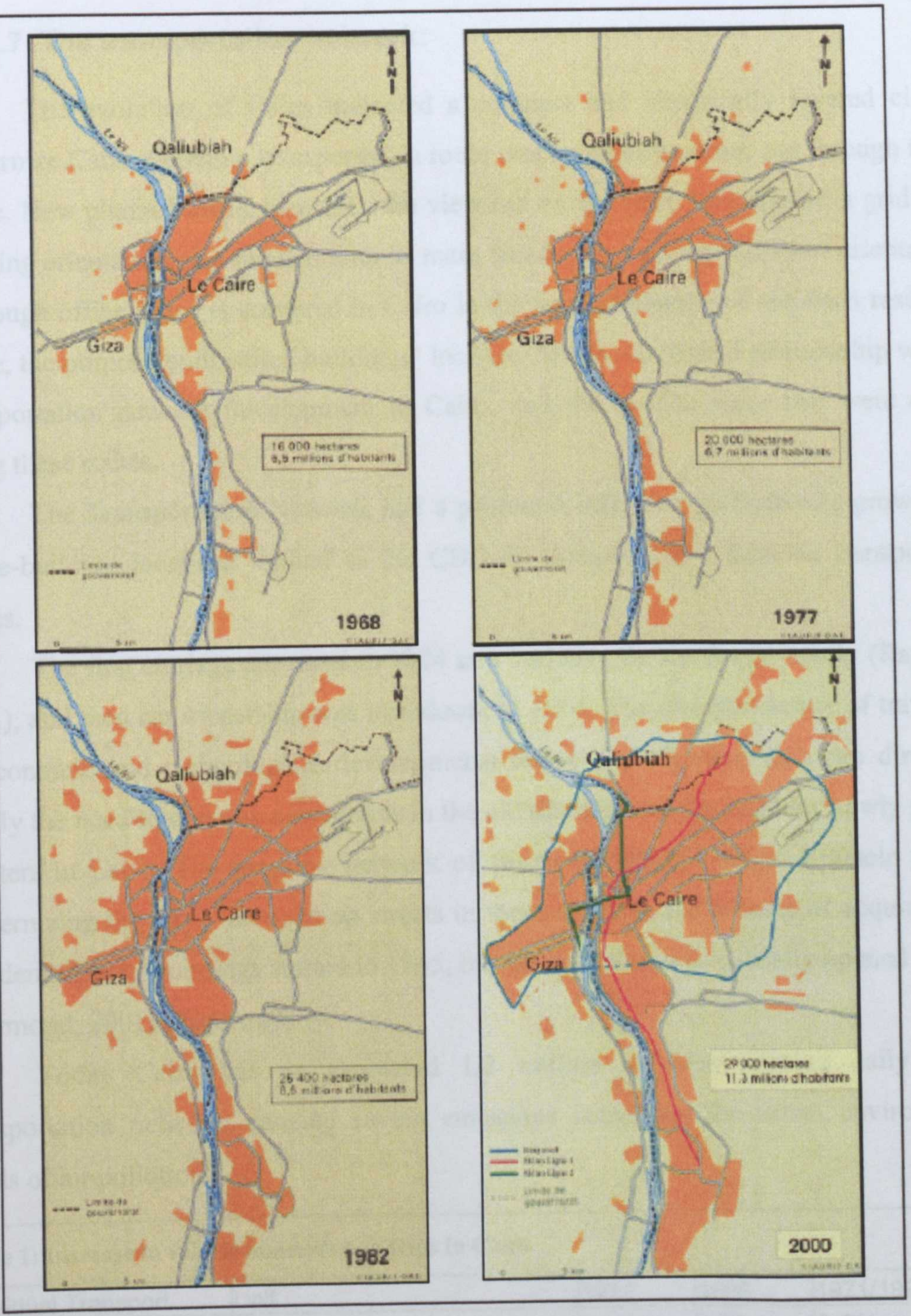

Figure 5: Cairo city growth and geographic limitations, Source (World Bank Urban Strategy Review (2000)).

2.2.1.7 The transportation network:

The evolution of Cairo indicated a compact and historically layered city. To modernize Cairo, planning transportation route was surgically carried out through the old fabric. New planned areas, respected the view out on the Nile. This created a grid where building orientation was situated with its main facades facing East and West orientation. Although office space is scattered in Cairo in the form of change of use from residential space, the purpose built office buildings' location has an interlinked relationship with the transportation network development in Cairo, and the service areas that were created along these routes.

The Transportation Network had a profound influence on both city growth, and office-building locations limited to the CBD or alongside new founded transportation routes.

The first carriage appeared in 1824 as a curiosity for the Royal family (Raymond, 2001), and then car ownership was introduced in 1904. The changed nature of traffic due to economic and technological developments drove city planning into two directions. Firstly the need to open up new streets in the old districts and the need for newly planned quarters in Cairo. The irregular network of streets remained a major obstacle towards modernizing the city. To open up streets in these districts, the process of acquiring lots and demolishing buildings started in 1845, but the first road was partially opened in 1849 (Raymond, 2001) (Figure 6).

Today Cairo has an estimated 1.2 million vehicles running daily on its transportation network, causing severe emissions increasing the urban environmental levels of air pollution.

Table 1: Increase in vehicle numbers and trips in Cairo

Individual Transport	Unit	1971	1998	1971/1998
Private Cars	Trips/ day (million)	0.42	1.87	345%
Car Ownership	Vehicles for 100 housholds	7.3	23.9	227%
Individual Taxis	trips per day (million)	0.26	0.56	115%
Total		0.68	2.43	257%

Source: SYSTRA household surveys (1971-1998)

Table 1, indicates the increases in transportation vehicles and trips made in Cairo, which indicates the increasing demand on the individual transport network between 1971 and 1998.

The load of traffic influx into Cairo and particularly its CBD, led to severe air pollution problems. The air pollution problem is aggravated by sand blown into urban areas from the neighboring Western Desert, as well as fumes from the industrial areas around Cairo with 60% of the national industrial activities, creating an almost permanent haze over the city. The concentration of total suspended particulate matter in Cairo is 5-10 times higher than World Health Organization guidelines, and on average sulphur dioxide is four times higher, smoke and lead three times higher, and nitrogen oxides two times higher (http://www.eia.doe.gov/emeu/cabs/egypenv.html)

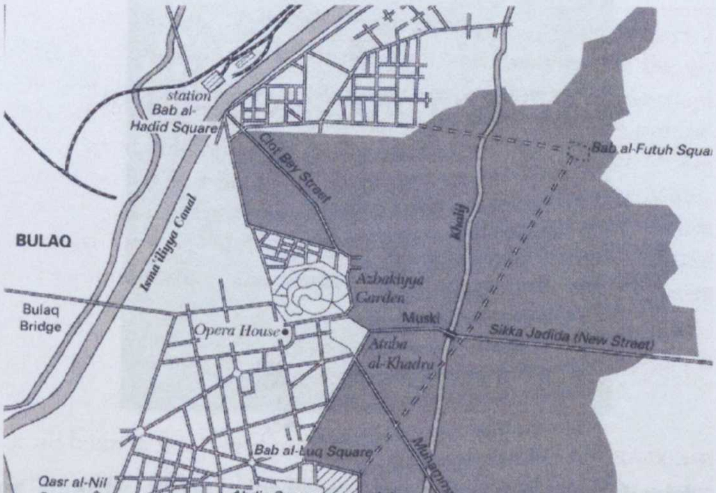

Figure 6: Cairo in the 19th century plan to form straight roads network in old settlements, Source Raymonds,2001.

Figure7: Dark patina on buildings due to air pollution

The deteriorated air quality raised concerns on its effects on health and the built environment. In the built environment facades became covered with a dark patina of pollution on the building facades (Figure 7). The Ministry of Environmental Affairs issued 'The Environmental Law' in 1994 adopting measures to decrease air pollution from transportation sources. Joint efforts in 1998 between the Ministry and the USAID were founded to monitor air quality through Cairo Air Improvement project (CAIP) to achieve World Health Organization Limits. Among these measures were the VET (Vehicle emission test) and enforcing the utilization of filters on industrial activities. The results of monitoring suspended particular mater in air in 1998 indicated the need for further action to reach the goal specified by the Egyptian Environmental Law no 4/1994. Figure 8: monitored levels of air pollution in Cairo still exceeds recommended WHO levels

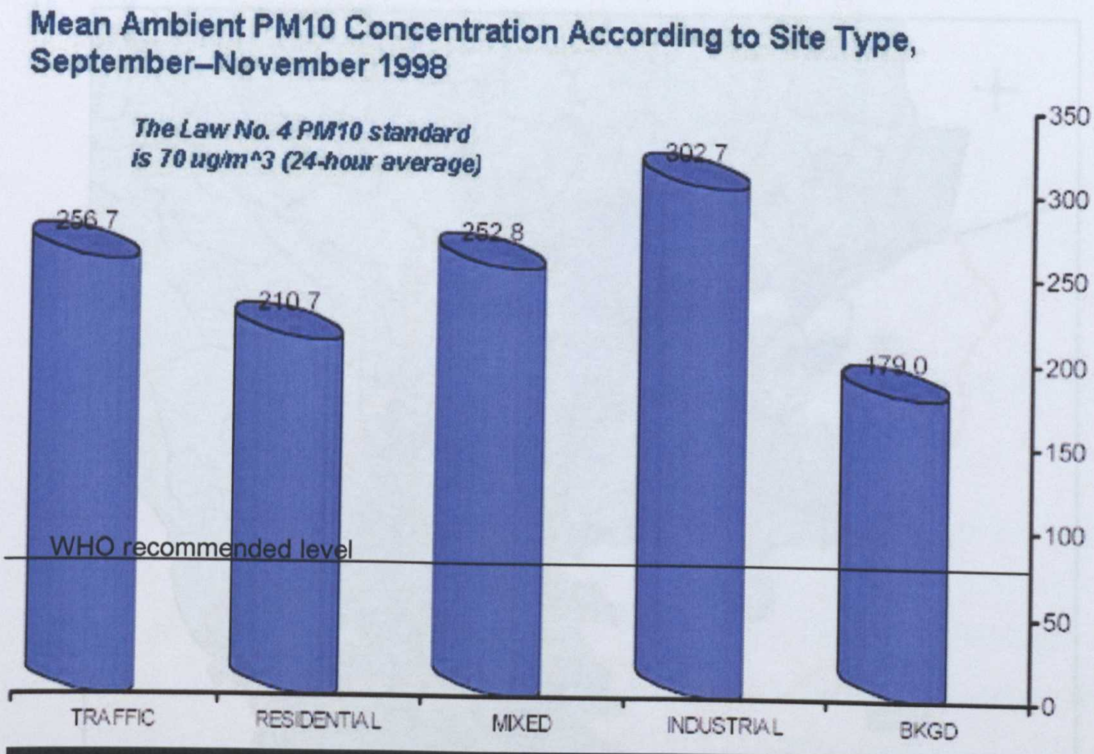

Figure 8: monitored levels of air pollution in Cairo still exceeds recommended WHO levels

The built environment interacts with the quality of the ambient environmental conditions; the previous section explained the current deteriorated state and quality of air in Cairo.

In this context, the deteriorated state of the environment, combined with the weather profile, sandstorms and high noise levels of traffic may be considered as a driver to isolate the indoor environment from the outdoor and therefore the need for air conditioning systems.

The concentration of workplaces (Figure 9) developed on both sides of the newly developed transportation and road network in Cairo's CBD.

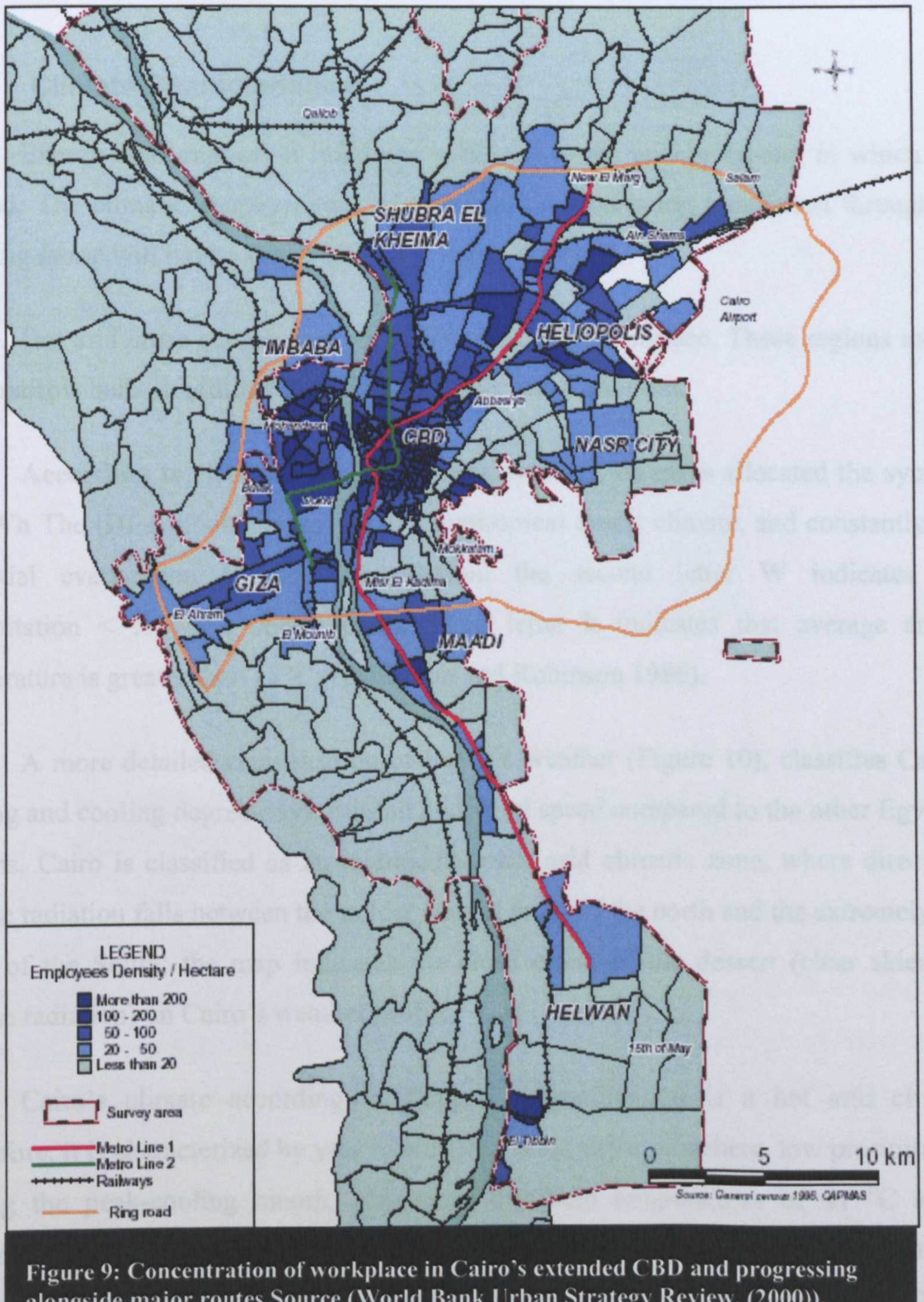

Figure 9: Concentration of workplace in Cairo's extended CBD and progressing alongside major routes Source (World Bank Urban Strategy Review, (2000)).

2.2.2 Climate Characteristics:

Energy consumption in buildings is related to the energy system in which it is located. The climatic characteristics of a certain location being transferred through the building fabric will have a direct effect on human comfort.

Hot arid areas occupy over one fifth of the earth's surface. These regions mostly lie in narrow belts straddling the tropic of Cancer and Capricorn.

According to (Koppen andTrewartha system): Egypt is allocated the symbols of **BWh** The **(B)** symbol denotes hot dry, subtropical desert climate, and constantly dry. Potential evaporation exceeds precipitation; the second letter **W** indicates that precipitation < ½ water consumption. Third letter **h** indicates that average annual temperature is greater than 18°C (Henderson and Robinson 1986).

A more detailed classification of Egypt's weather (Figure 10), classifies Cairo's heating and cooling degree-days, rainfall and wind speed compared to the other Egyptian regions. Cairo is classified as an intermediate hot arid climatic zone, where direct and diffuse radiation falls between the milder coastal areas of the north and the extremely arid areas of the South; the map indicates the close effect of the dessert (clear skies and intense radiation) on Cairo's weather profile.

Cairo's climate according to Koppen's classification is a hot arid climate. Therefore, it is characterized by year round clear skies, dry atmosphere, low precipitation. During the peak-cooling month, Maximum dry bulb temperatures of 41 °C and a minimum of 21 C by night are recorded. Over a 28 year period of climatic monitoring occurrence of temperatures for 97.5% of the year in summer month is around 35 °C. It is important to note that climatologic data only provides temperatures in the shade and do not account for urban heat islands.

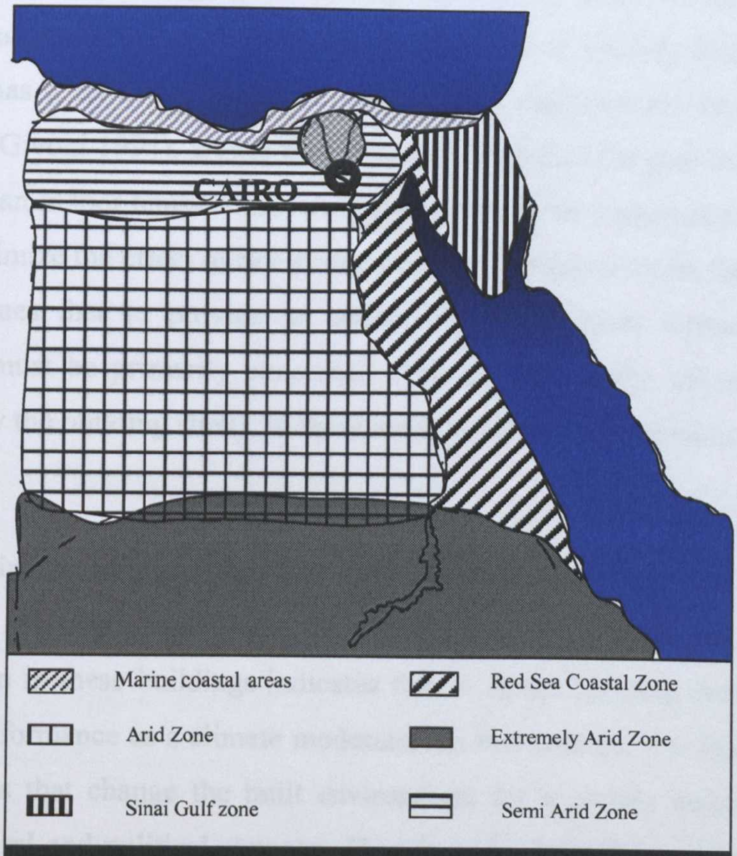

Figure 10: Detailed Climatic Classification of Egypt

Arid climates are also characterized by sandstorms that vary in their intensity and settling times necessitating air inlets to be positioned as high as possible with a minimum of 2m above ground level to avoid minor and frequent sandstorms. Cairo is characterized by a permanent haze that is partially attributed to the size of particles falling on the city due to sandstorms generated from the surrounding Western desserts. As particles tend to be smaller (2 microns) a minor dust storm may create a permanent haze. With particle sizes and wind speed varying, it may take from 1hour up to 15 days to clear after a sand storm (CIBSE 1990)

Buildings envelopes in this case act as a buffer between the outdoor and indoor conditions. As a result of heat transfer by convection, conduction and radiation, building fabric heats up during the day and cools down during the night. These natural cooling down processes occurs even without integration of passive or active means to a building.

Day time heating and night time cooling result in an indoor temperature that is higher than the outdoor average. Even if the windows are effectively shaded and the building envelope has a reflective colour, average indoor temperature remains higher than the outdoors. (Givoni 1994), argues that in hot arid climates the goal for a building fabric is to achieve an indoor temperature, similar to the outdoor temperatures measured in shade and to minimize the effect of Sol-air temperature elevations on the building. While (Saini 1980), argues that to provide an acceptable environment without air conditioning, designers must be primarily concerned with controlling the micro-climate (the space enclosed by the building shell). In these areas reduction of heat takes precedence over air movement.

Building facades in Cairo that were originally constructed to deal passively with the climate are now plagued with air conditioning units. It may be argued that energy consumption in these buildings indicates failure of the building envelope to achieve its targeted performance as a climate moderator. In this context, it is important to recognize other factors that change the built environment for a certain community triggered by social, cultural and political changes. Therefore the following section will focus on the changes in Cairo's built environment as a whole, then focuses upon changes in façade design and its effect on energy consumption.

2.3 Historical Development of Cairo's Facades

This section aims at reviewing the various factors that created and influenced the built environment of Cairo. This identifies how the demand for energy has changed during the various phases of the cities growth.

2.3.1 The Evolution of Façade Design

The shift away from the traditional urban environment of Islamic Cairo, into a global image of a city had its impact on energy consumption in buildings. It is important to understand the drivers behind this change, to explain the increase in energy demand for Cairo.

While Europe was overtaken by the principles of the strict Vitruvian model and renaissance principles in planning and presentation of external facades, different social values prevailed in the Islamic world that affected the built environment.

In Islamic and Old Cairo districts, in response to both climatic and religious philosophies of equality, humility and respect for neighbours rights and privacy, the urban fabric continued to evolve around the inherited urban forms of settlements from ancient Egyptian times. Urban densely packed residential blocks and irregular streets formed the city fabric providing shade to exterior facades and protecting it from direct solar radiation (Figure 11). The awareness of the importance of providing shaded areas to perform daily activities is founded in all building types. The general market place 'Souks' took place in roofed streets between residential blocks. Urban districts focused on the mosque, school and baths around which enlarged courtyards accommodated workshops and markets. Mosque courtyards were surrounded by colonnades (Similar to the Agora and Stoa principles).

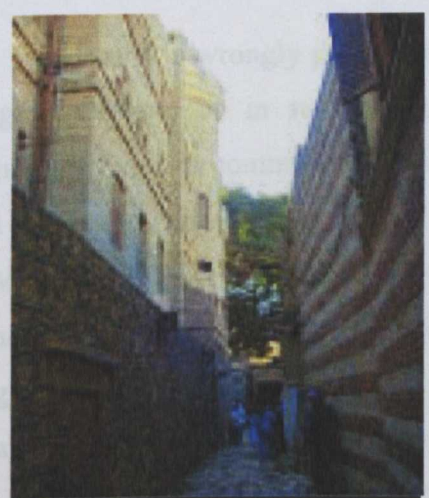

Figure 11: The urban setting providing shade to exterior

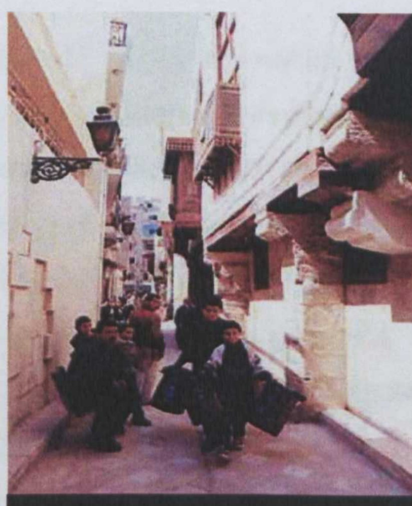

Figure 12: Stark simple walls overlooking Alleys in Old Cairo

Here the façades were merely to reflect the conservatism of the society, built to give the exterior a stark simple wall, with only the portal lavishly embellished. The outward façade was not considered important, buildings are self effacing, giving no indication of the importance neither of the building nor of its interior spatial organization (Fletcher 1996), (Figure). Although a focal planning point, the mosque was usually obscured by buildings of secular nature, such as covered market places (*suqs*), and baths (*hammam*). For climatic modification, public as well as residential buildings shared the facade features of minimum shaded openings to the outside. The grandeur of the buildings was only revealed after entering through the portal passage. All elements of surprise and appreciation for beauty and peace of a building were reserved for the inside court, gardens and facades overlooking them. The court performed as a climate modifier providing shaded air temperatures away from direct sun radiation. Building facades were used to define the space in different manner than that used in the Renaissance time in Europe. Not reflecting institutional wealth or power to impress the public, but only a sombre appearance to daily life, with a promise of a piece of heaven hidden inside. The maximized population offered defensible perimeters and improved the microclimate, and a short walk distance for supply of water.

Often it is wrongly perceived that Islamic architecture evolved solely from strict religious orders, or in response to climatic conditions. The greatness of Islamic architecture was its commonality of architectural attitude from the seventh century till the end of the 18th century in the lands it spread through from Indonesia and India to the East to Morocco and Spain in the West (Khan 1978). Islamic architecture was founded on the principles and willingness to adapt to local materials, climate and local image (Figure 13).The use of mass on exterior walls although for structural purposes provides a delayed transfer of absorbed heat during the day to the interior spaces.

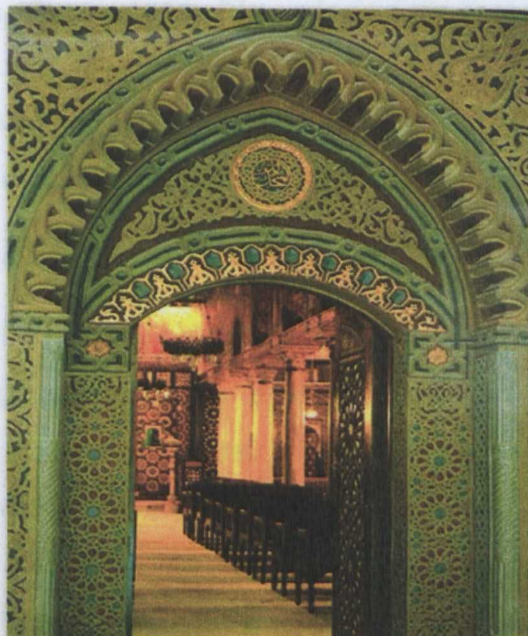

Figure 13: The hanging church entrance details, later in Islamic eras the massing and decorative motifs are found in various building types.

There appears to be a general attitude to hold to the thread of architectural continuity while applying the teachings of Islam. Facades and building design principles in Islamic regions evolved over a long period of trial and error (Appendix 1, chronological order of since Arab conquest).

From the date of the first Islamic conquer of the lands (642 A.D.) architectural concepts acquired due to invasions of Middle East countries fused with the local Coptic architectural elements and there evolved with a style of its own, responding to a design program for each building function. From literature it appears that only public buildings and residential houses for the rich merchants were constructed with the utmost detail. The last great building is the mosque and tomb of Kaitbey erected at 1472 A.D.

Under the Ottomans rule, Egypt became merely an estate in their empire in 1517 A.D. (for almost 350 years). Cairo returned to the dispersed patterns of settlements. The growing disorder of the city plan and the difficulty of communications confirm the precipitous decline of the city. It came to be no more than an aged city ruined by anarchy,

devastated by epidemics (Clerget 1934). The arrival of the French occupation in (1798-1801 A.D.) marked the end of the architectural continuity from Mamluk to Ottoman times and the change of the urban state of Cairo.
The political change allowed Muhammed Ali to announce Egypt an independent state from the Ottomans and then to organize a new government, a new society, and a new economy.

Since 1517 A.D. till the reign of Mohammed Ali (1805-1848) the built environment was left to deteriorate, no advancements in the building concepts, regulations or old art were achieved. In Cairo, little change occurred till the reign of Isma'il Pasha in (1863-1936).

The emergence of the neo- classical architecture in Egypt and the effect of westernising the culture (Ferguson: 1893:p.535) criticized the drive away from improving and continuing the existing architecture style. '*when a new age of splendour appears, the old art is found to have died out, and a renaissance far more injurious than that of the west, has grown up in the interval*" (Fergusson and Spiers (1893)). It is evident that society's perceptions were changing due to the increasing dominance of the Western style buildings and the organization of buildings along Western concepts of order. Though some architects promoted a neo-Moorish style between 1870-1930 as a final effort to preserve authenticity, this style finally retreated to decoration. Attempts to design windows with wooden lattice *'Mashrabiyas'* were residing too. (Ilbert and Vollait 1984) explain that using Islamic or neo-Moorish style building models introduced a further segregation between the social levels of the community. They were to be considered as merely a veneer to a building façade as Western style plans were widely adopted by the time. To encourage the adoption of the Western style arrangement of indoor spaces and façade configurations a law banned the use of *mashrabya* on windows nominally for safety reasons but probably to legislate modernisation. The use of glass windowpanes was encouraged, a style that was imported basically from Turkey (Abu-Lughod 1971). An eclectic form of architecture and façade treatment appears by the late 19th century (Figure 14).

Figure 14: Façade shading systems in Neo-classic Cairo

Left: Eclectic use of *mashrabya* as a veneer for a Neo-classic Western Style Apartment building.
Right: A public school (sabil Kottab) in 1870s by Italian architect Pantanelli. Eclectic form of architecture, using wooden shutters for shading instead of Mashrabya
Photos courtesy to Ilbert R, and Vollait M.. (1984).

2.3.2 The Need for Corporate Image:

In Egypt, Muhamed Ali Pasha (ruled 1805-1848 A.D.) launched a major institutional and economic reform by shifting the countries economy from agriculture to industrialization. This transition brought in its league the adoption of institutionalised administration methods that were foreign to the previous Ottoman ways. This rapid emulation of the Western institutional methods aroused an intrinsic need of new technologies and functions to be accommodated in buildings (Serageldin and Vigier 1983). Western forms and styles were adopted as the Islamic countries had no easily indigenous style or form to adopt these functions, such as transportation terminals, offices, banks and factories (Figure , Figure 16, and Figure 17). Implicit to the debate on loosing the regional character of architecture was the questions, how can traditional cultures be maintained or revived without loosing the benefits of modern technology?. The strength of Islamic art and architecture has traditionally been laid in unity through diversity

The need for office space emerged with the industrialization of Egypt in the mid Nineteenth century as part of a factory or a change of use from residential to office space. With the exception of institutional buildings (as a form of office buildings), office buildings appeared as a separate building type by the end of the 19th century.

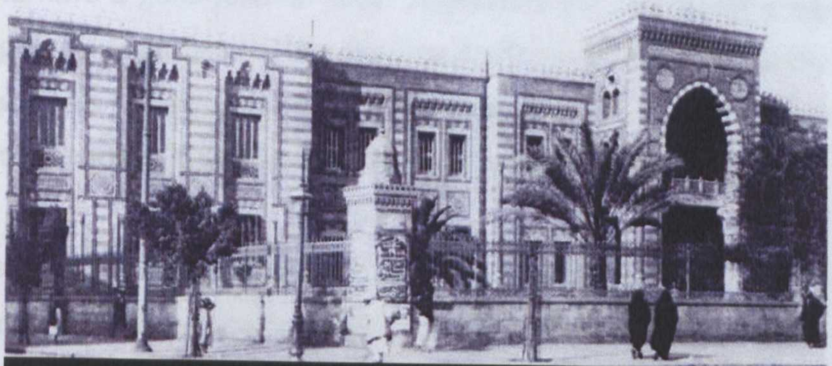

Figure 15: The Waqfs Ministry Building, Cairo 1925: by architect Mahmoud Fahmy Pasha

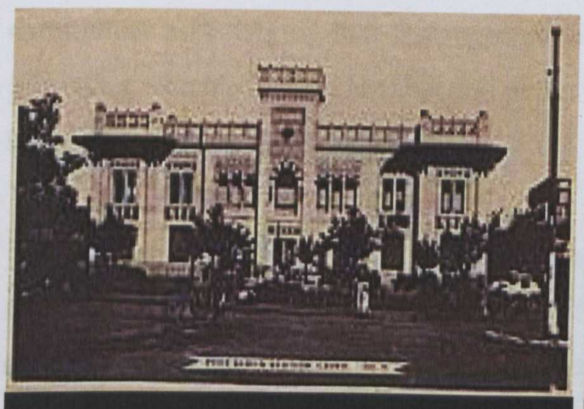

Figure 17: Bab el-Lamon Rail Station in Cairo, with its Neo-Arabic Renaissance façade, late 19th century.

Figure 16:Misr Banque Building, 1927

The major influx of Westernised architectural thought in Egypt dates back to the late 18th century, in line with the start of the French occupation of the lands (1789-1801). By the late 19th century, the changes in social perception of what was to be considered a well-designed building appears in writings suggesting a whole change in cultural acceptance of the old inherited building facades and building forms. Referring to the emergence of the Noe-classic Façade and its intention to impress people with its artistic and detailed richness,(Mubarak 1888) observes that '*Today people has abandoned old ways in construction in favour of European style because of its more pleasant appearance and reduced building costs. In the old system facades never followed any geometric order thus looked like those of cemeteries. In the new system facades are ordered and have a good familiar look*' Apparently the general taste was shifting into considering the straight lines of the Western architecture, the benefits on hygiene from increased amounts of daylight and fresh air entering spaces. This change was concurrent with the introduction of Neo-classicism as an architectural style in Cairo.

The abrupt adoption of building facades of neo-classicist in Cairo and many of the other Islamic cities has been attributed to the perception of the need for the local governments to compete on a large economical scale with the colonial super powers.

Under the successive reign of the Muhammed Ali descendants, governments assumed a broader range of responsibilities, replacing the religious authorities, community associations, and charitable institutions that were traditionally responsible for providing worship places, schools and parks. This shift in responsibilities created an ever-increasing demand for office space.

The international style was introduced in Cairo in the mid 1950's. Cairo was submerged in a crude form of modernism. Facades followed a minimalist approach for speeding up construction while reducing costs (Figure 10). The image transfer also included copying of methods on controlling the out door ambient environmental effects on indoor thermal comfort.

Figure 18: Vet. Services Building (early modernism in Cairo).

The European model of shading building was utilized, although the residential style wooden shutters would be used on windows of public buildings, vertical and horizontal concrete louvers was a popular design solution (brise-soliel). Facades were designed with few straight and perpendicular lines reflecting mechanically the structural grid and a rhythmic monotonous order of simplistic notion of functionalism. It is argued (Asfour 1998) that during the first 20 years of image transfer, Arab cultures were eager to practice this simplistic version of modernism to give them a fresh visual start, which would mark their independence from 19th century colonial powers. It was regarded as a notion of progress, and only building facades could reflect it. Inherited architectural styles were not examined for improvements. A culture of cut and paste from Western facades immerged (Asfour 1998). In Cairo buildings constructed between the 1960-1990 were constantly criticized; *'Some may tell you that apartment and office buildings East and west of the Nile built between 1960 and 1990 should be written off as instant council houses (as a symbol of ugliness and poverty). They are, to say the least, void of any architectural appeal'* (Raafat 1999).

Till the 1980s, office buildings in Cairo were designed for natural ventilation, with shaded openings. Though it is evident that these buildings would not rely on high electrical consumption for a mechanical cooling system, there is no account of whether these buildings provided thermal comfort to its occupants. In the 1980's with building materials and techniques being exported, completely sealed office buildings appeared, with a their dependence on electric consuming HVAC systems. Parallel to the trend naturally ventilated office buildings were equipped with window or split type air conditioning units.

Figure 19: Office buildings of the 1980's- Aboul Fetouh Building in Mohandeseen

These highly mechanical serviced buildings in Egypt are attributed to a number of factors:

- Increased glazing areas were a potent symbol of architectural modernity, social progress, and organizational prestige. Thus higher rental levels could be demanded, giving higher profit margins for investors and
- Cheap energy, the running costs of the buildings were not sufficiently high to encourage investigation of alternative servicing methods.
- As was recognized in Europe and USA, in many ways these systems were effective in excluding the deteriorated external environment and high air pollution levels in Cairo. Filters allowed the removal of outdoor pollutants, ductwork

systems with attenuators were able to reduce external noise significantly, and cooling permitted comfortable temperatures to be maintained in the hottest conditions (Thomas. 1997)

- Office space in Cairo is generally leased from the building owner. Each occupant (whether an organization or a single occupier) of the leased space is responsible for paying their own energy and services bills.

In the early eighties iconographic office building facades appeared, depending mostly on utilizing greater areas of window to wall ratio. Over the following decade the illusion with the fashionable architecture style waned. The artistic trends in these buildings that strived to dispense with climatic solutions in favour of providing fashionable facades that would attract attention of passers by and trap users in a thermally uncomfortable environment. An indoor environment that proved too costly to control.

In many developing countries of the world the criticism of architects copying the international style were pronounced. Architects were criticized as being swept away into the tide of industrialization and Westernisation that lead to a severing between cultural identity and historical linkages between the imported and the regional architecture (Powell 1983) and (Beng 1994)

Facades in Egypt now and specifically in it's capital Cairo are at a cross roads, whether to follow trends of regionalizing modernism, or keep on cloning the architectural images of the west. Refurbishment of office building facades is included in the dilemma. As major owners and companies tend to refurbish the existing office stock, major alterations are normally undertaken for the facades. In this context it is of importance to highlight the benefits of incorporating enhancements to the façade thermal performance to decrease dependence on air conditioning systems (with their unfavourable dependence on energy) to achieve indoor thermal comfort, while adopting a sustainable strategy to refurbishment.

2.4 Energy consumption and the Built Environment

Awareness of the expanding dependency on generated power in buildings started in the late 1960s by writings of Olgyuy (1953) and (Banham, 1969). But, it was not till the 1970's that the issue of controlling energy in buildings were addressed worldwide in response to three tides:

The first energy crises in 1973 necessitated the need to regulate energy consumption in buildings. Legislations attempting to enforce the rational use of energy were issued in fuel importing countries date back to the mid seventies. Under different joint organizations such as the IEA (International Energy Agency)[1], countries joint forces seeking to provide sufficient energy to fuel economic growth, and to ensure energy security. Efforts to reduce dependence on imported oil and to save energy were at the centre of policy action.

The second wave was in the 1980s, when trans boundary problems related to acid rain (SO_2 and NO_x emissions) brought new challenges. This strengthened interests in promoting energy efficiency as a means to reduce the impact of energy production and use, carbon dioxide emissions, ozone depletion and global warming.

The final wave appeared gradually during the 1990s. Energy policy priorities shifted, partly due to changing attitudes towards the role of government in energy markets and in response to climate change. Concerns within the global context continue as world energy consumption grows by 2% per year on average, but with energy consumption in some of the emerging economies increasing yearly by 6% or more. In absolute terms however, the increase per capita is still higher in developed countries. This rise in non-OECD energy consumption is leading to important changes in energy markets in South East Asia and

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[1] http://www.iea.org. (The International Energy Agency, based in Paris, is an autonomous agency linked with the Organisation for Economic Co-operation and Development (OECD)
This organization includes 24 oil importing countries, 17 of which joined in 1976-78 (the first Oil crisis) namely USA, UK, New Zealand, Switzerland, Austria, Sweden, Spain, Netherlands, Luxemburg, Japan, Ireland, Germany and Belgium, Canada, Denmark , Greece, and Italy. * other countries joint early in 1980 (the environmental awareness stage), namely Turkey and Portugal, while France, Finland joined in 1992

potentially around the world and to significant changes in the traditional patterns of energy flows from the energy exporting countries. There seems to be several reasons for the global interest in reducing dependence on and consumption of energy within the built environment. Government's interest in flattening the demand of energy is directed towards cutting down peak demand, which determines the need for increased generation capacity, as well as reducing annual consumption of these buildings.

Egypt passed a National Environmental Law in 1994, and is increasingly concerned with the protection of the environment and conservation of energy. The government is preparing a national climate change action plan and a national strategy for improving energy efficiency in Egypt.

2.4.1 Electricity consumption in Egypt:

Production of electricity in Egypt depends mostly on fossil fuel amounting to 76% while only 24% of electricity is produced from hydro sources, no other sources are available (http://www.odci.gov/cia/publications/factbook/eg.html#gov). Oil accounts for 92% of Egypt's primary sources of energy, besides being a mainstay of national economy as a source of foreign exchange revenue through its export to other countries. Egypt oil production has declined (from 922,000 bbl/d (barrels per day) in 1996, to an average of 866,000 (bbl/d) of crude oil during 1998. With domestic oil demand increasing due to economic growth, there are fears that the country could become a net oil importer by 2005-2010. Egypt's net electricity consumption, increased in less than a decade by 54% (1988 till 1997, from 32.9 to 50.9 (Billion Kilowatt hours) (http://www.eia.doe.gov/emeu/international/egypt.html), with an annual increase in electricity consumption between 6-7% (Figure 20) (http://www.sis.gov.eg.). The built environment consumes 52% of the gross national production of generated energy. In 1998 Egypt ranked the 29th country among 125 countries reviewed in electricity consumption; the second major in Africa (after South Africa). Per capita energy consumption in Egypt rose above China and India (http://www.iea.org/stat.htm).

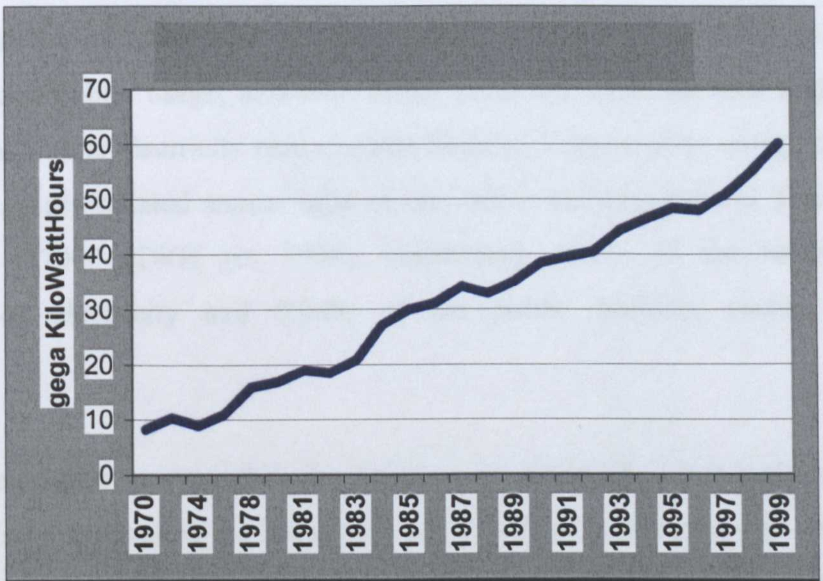


Figure 20: Total electricity consumption in Egypt

Attributing to this sector's rising energy demand is the building envelope configurations. Building envelope plays the role of moderating the outdoor environmental and climatic conditions. The increasing reliance of public buildings on air conditioning systems indicates the failing role of the building envelope to perform its function as a moderator.

To understand the reasons behind the failure of the envelope to manipulate the outdoor conditions and provide indoor comfort it is pertinent to analyze these buildings in a wider context of their existence within the city, and factors affecting the evolution of their building envelope in Cairo.

2.4.2 Energy Use in the Building Sector in Egypt:

The building sector combining residential, governmental and public buildings consume 52% of the total generated electricity power in Egypt. The building sector's electricity consumption is divided into, the public and governmental building sector consuming 18% compared to 34% in the residential sector (Table 2 and Figure 21).

The number of residential buildings by far exceeds those buildings used for governmental and public usage; however, office buildings stand out as a major energy consumer in the public electricity consumption domain. Compared to energy production levels of 1998, Accumulated annual bills of one office building (World Trade Centre) amounted to 427000 KWH (in 1998), constituted 0.01% of the national gross consumption of electricity and 0.06% of the public building sector electricity consumption.

It is important to note that the increase in electricity consumption in office buildings is also attributed to the increasing use of office equipment, and the aging of their cooling systems that depend solely on electricity for operation.[2] This phenomenon deserves analysis for its cause and possible ameliorations to decrease the building energy consumption holistically.

Table 2: By sector share of electricity in 1998

Type	Billion KW/hr
Industry	21
Agriculture	2
Residential	17
Governmental buildings	2.5
Public buildings	6.3

Table 2: Electricity consumption by Sector
Source: http://www.sis.gov.eg

[2] Interview wih Eng. Ashraf Assem (Building Manager of the World trade center in Cairo) on 25th of Dec.2000

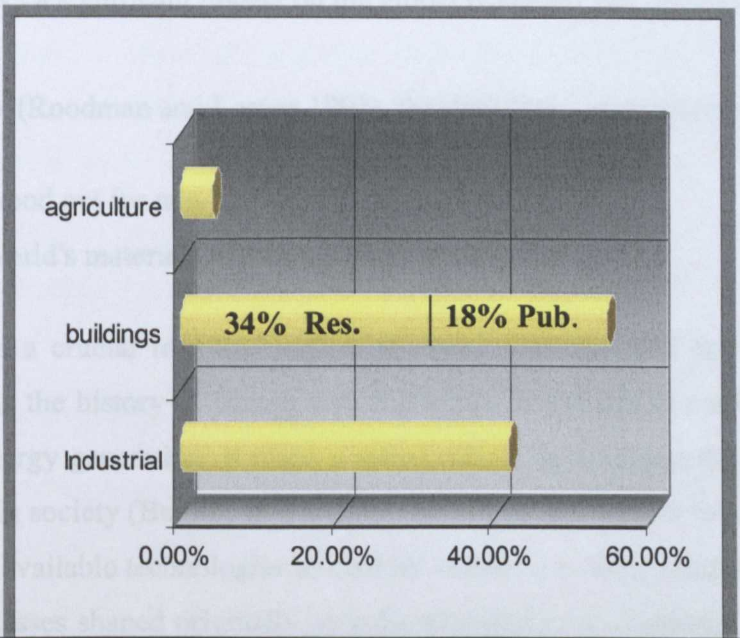


Figure 21: By sector electricity consumption in Egypt

2.5 Energy Use in Buildings:

The energy Crisis of the 1970s provoked a fundamental change in architectural design. In the past 30 years, the environmental agenda in architecture, in both practice and research, has undergone an observed radical transformation, supported mainly by changes to building regulations that would drive the architectural profession into energy consumption consciousness.

The built environment is analogous to a living system, which survives by importing energy and matter from its environment in one form and then exporting it back into the environment after use. A building is a transient phase in which people assemble a quantity of energy and matter into certain predetermined patterns and forms of use (Yeang 1995).

Buildings have a significant impact on the global resources and environment, research

According to (Roodman and Lessen 1995) that building construction consumes:

- 55% of the wood cut for non-fuel uses is for construction
- 40% of the world's materials and energy is used by buildings

Energy plays a crucial role that underpins social advances and cultural evolution. Human history is the history of energy transformation. Every era is marked by its own techniques of energy generation. It plays a major role in determining the prosperity and power of a certain society (Behling and Behling 2000). Its availability to a certain culture is a function of available technologies to exploit/ conserve it, depending on political and economical processes shaped originally by cultural institutions. If energy is the invisible power behind nations prosperities, and if prosperity of nations is measured by their technological achievements, and their wealth by the natural resources they manipulate, then the built environment stands out as a resultant and evidence of the these factors combined; energy, natural resources, available technology, and the know how of using them. Architecture has frequently been the medium through which man has symbolized his attitude to nature, and its reserves of energy resources ranging from adaptive to assertive. The architectural product redefines the interaction between a building and its environment. Buildings as a human intrusion act upon an energy web in relative stability, the building requires energy to sustain its activities introduced to the specific site from different sources thus modifying the biological structure of the earth itself (Odum and Peterson 1972).

The embodied and operative energy are the two main areas where buildings consume energy. The understanding of energy consumption in these two areas is crucial for energy conservation within the built environment.

2.5.1 Embodied energy:

The building and its facades redefine architectural design as a form of energy and material management. The building then acts as a resource modifier, where the earth's energy and materials are managed and assembled by the designer into a temporary form existing for the period of use of this structure. At the end of the period of use the building is demolished, with materials either recycled within the built environment or assimilated into the natural environment (Yeang, 1995:18).

(Lawson 1995) identified four criteria to asses embodied energy with a certain construction. Embodied energy is concerned with the consumption of non-renewable energy sources to:

- Extract materials (locally or imported)
- Transport building materials from their different sources from raw material sources to manufacturing facilities then to site
- The energy used to transform raw or recycled materials to finished products
- The energy used in operating construction equipment.

For new office buildings a whole, the embodied energy ranges from 3.5-7.5GJ/ m^2 of floor area whereas energy in use amounts to between 0.5-2.2GJ/ sq. m annually. Typically, the initial embodied energy of an office is equivalent to about five years of energy use, or about 7% of the total energy used over the lifetime of the building (Howard and Sutcliffe 1993).

With consideration for energy used in manufacturing components and delivering the building as a product, it is argued that refurbishment is better than re-development of building sites as it creates an opportunity to save the embodied energy used in the original structure.

2.5.2 Operational energy:

Buildings consume energy principally in the process of environmental control. (Hawkes, 1982). Operational energy defines the energy needed to operate a building to attain visual and thermal indoor comfort, safety and health for occupants. The magnitude of operational energy use is dependant not only on the quality of construction and the building systems' provisions but also on the broader sets of physical properties of the site and its macro/ microclimate and temporal dimensions affecting users of a certain building type. Within the building, operational energy has a direct relation to façade design and symbolic expression. A historical review will give insight on how the utilization of energy used to modify or control the indoor environment has affected façade design and expression (Chapter 2, in 2.5).

There is a continuous cycle of energy use in buildings rotating between embodied and operational energy. Initially embodied energy is used, then operational then embodied energy (during refurbishment and maintenance), then operational energy again then finally embodied energy when the building components are demolished or recycled.

With the increased concern for energy use, it is put forward that appropriate and sympathetic to micro-climate building design assisting in savings in energy used for building operation. The integration between the physical performance of the façade and building systems is paramount as current building systems depend on non renewable sources of energy that increase the emissions of carbon dioxide, leading to operational costs exceeds overtime the capital costs of buildings (Thomas 1999). This condition focuses design efforts on re-integrating passive systems and optimising the utilization of active systems.

Several concepts have been recently under scrutiny to answer the question of how buildings can reduce reliance on energy through efficient façade design through

- Reuse of passive/hybrid systems. Evolution of double skin façade/ intelligent controls.
- Zero energy concepts (depending on increasing thermal mass / or building envelope insulation)
- Integration of energy generating technologies and facades (Photovoltaics technologies and solar cells)

2.6 Expression of operational energy in façade aesthetics:

The thermal performance of a building is influenced by the configuration of its envelope. Façade configurations, especially in office buildings, are designed to reflect advances in building materials technologies, institutional wealth, and act as state of the art buildings. Advances in glass production led to construction of the fully glazed office building façade. Transparent filigree buildings became the recognition of modern architecture since the 1920s. German writer, Paul Scheebart, envisaged that taking the closed character from rooms by using glass walls will lead to a change in culture (Scheebart 1914). Leading architects like Mies Van der Rohe (1886-1969) in describing his theory in Seagram building, and the utilization of glass and bronze to clad the building's structure in an attempt to move away from classical architectural design to developing new forms from the very nature of the new demands for work spaces. Mies advocated the use of glass as a new exterior wall construction material, based on the new structural principles of the skeleton building where the envelope became non-load bearing (Blaser 1997). Mies's ideas invited office-building designers to exploit the limits of technology, knowledge and materials to reflect the economic and aesthetic value of these buildings. The international style-recognized as modern architecture dominated the construction of several office buildings worldwide. The universal Mies van der Rohe's rectangular, open plan, that could house virtually any function, dominated office-building designs. Office buildings were constructed unresponsive to site, orientation, climate or native culture. Although the use of glass on exterior walls provided visual connection to the outside world this was not without a penalty of decreasing indoor comfort by increased levels of glare and increases of heating levels to compensate for thermal heat loss from the building facades.

It was not till the 1980's when a leading article by English Architect Mike Davies (Davies 1981) ' A Wall for All Seasons', addressed the possibility of using the building skin as multiple-performance glazing, which could dynamically regulate energy flow through the building.

Further awareness of the need to achieve an improved environmental performance from the façade was aided by the technical achievements of glass properties and constructional methods. Re-integration of building services in the fabric was realised leading to what would be termed: 'climatic facades', 'Double skin facades' or 'multi-layered facades'. Following the oil embargo in the early seventies, attention given to building services was progressively being attacked from architects. The realization that buildings that were excluded from site and climate location and their impinging needs on natural resources to be functional for human use and comfort drove the architects interest against mechanical ventilation systems. The tradition of a long architectural profession without architects, and how these earlier buildings provided a perceived comfort for its occupants waned the confidence of architects in their own ability to deal with energy problems or opportunities for energy saving technologies. Calls for buildings to retain their traditional modes of inherited construction, location and orientation received publicity. Rather than calling for more efficient air-conditioning, the call was for abandonment of air-conditioning, no matter if on the expense of the comfort of the modern user. If lightweight envelopes were poor insulators then the call was not for better insulation but for heavy weight structures in traditional masonry.

If the traditional ways of building are regarded the most appropriate way in building, then it must not be forgotten that buildings always depend on energy to attain comfort for its inhabitants. The human race at large has known from experience that an unaided structure is inadequately comfortable, Fires have been lit in the evening, oil-lamps were used, and in hot humid arid and humid climates muscle power was used for fans, and water for fountains for the heat of the day.

Building fabric plays a major role on building operational energy. Its effect varies according to specific site location (urban or on the city outskirts), construction materials, and site geographic location as mentioned in the previous sector. Heat transfer occurs as natural phenomena in four distinctive routes, namely conduction, convection, radiation and moisture transfer.

The definitions of how building fabric will affect the use of energy have generally passed by three phases;

2.6.1 The Late sixties:

The relation between the building fabric and the need for the building to consume energy to achieve indoor thermal comfort has been classified by Banham (1969) into three distinct modes of environmental control: Conservative, selective and regenerative.

Conservative mode: in which a thick massed buildings (or in more sophisticated buildings using special property glass as a filter to discriminate between light energy passage and barred heat energy), have the property to store and release heat when needed.

Selective Mode: that expels unwanted conditions from within to admit desirable conditions from outside.

Regenerative mode: where applied energy is utilized to achieve human thermal comfort, and control the air quality of indoor spaces.

2.6.2 Early 1980s:

The previous classification has been adapted by (Hawkes, 1981 :25) but modified to become: The Selective and exclusive mode.

The selective mode: combines Banham's selective and conservative mode to acknowledge the dual function of a building fabric as both an admitter and excluder of the external environment.

The exclusive mode: acknowledges the primacy of 'applied power' as in Banham's regenerative mode, but views the effective use of energy as being dependant upon building fabric in a manner related to Banham's traditional conservative mode.

The basic distinction between the two types is that the selective mode building makes use of ambient energy as a major source. The exclusive mode depends predominantly upon generated energy.

However not only will the building's design mode affect its design concept but its seasonal demand of energy. In a hypothetically entirely exclusive designed building, the building would consume some generated energy at all times when it is in use, but the peak demand would be small and not dependant on seasonal variations. The selective building on the other hand is expected to consume some generated energy for thermal comfort and lighting during extreme weather conditions, but it should be possible for the building fabric alone to provide a comfortable environment for substantial part of the year.

2.6.3 The 1990's

During the late 1980 and early 1990, the major advancements in building automation opened the way to construction of buildings more responsive to their environments. The term Hybrid buildings though appeared in literature in the early 1980 did not materialize into usage into actual buildings till early 1990's. It appeared into classifications of the relation between the building fabric and the building's energy consumption as Passive, active and hybrid. (Hyde, 2000)

The passive building mode: where the building uses no plant or equipment to modify the climate (previously defined as selective mode) The building fabric regulates the external environment but internal temperatures follow fluctuations of the external environment.

The active building mode: similar in definition to the regenerative and exclusive modes.

The Hybrid building model: The term was coined in early 1980s (Berry, 1982:78) where the building adopts both active and passive building strategies to modify the indoor environment. Passive systems are used as far as the building fabric is able to act as an environmental moderator. Plant and equipment are only used as trimmers, in extreme indoor conditions generated from either excessive casual gain from occupants or from environmental loads. But while strengthening the role of the fabric to regulate and reduce energy consumption. These controls rely heavily on building management systems and were made available by the improvements in IT systems. Computer systems, which monitor the building performance in use and can automatically, regulate the building thermal performance to optimise building energy efficiency.

The hybrid system or 'mixed mode environmental control' (CIBSE AM10, 1997) is divided into two modes.

Zonal mixed mode: in which different parts of the building are serviced in different ways to cater for different uses of the specific space.

Seasonal mixed mode: in which utilization of active environmental control systems are alternated with the passive approach according to the season, where the active systems are used to control indoor comfort conditions in relation to utilization of space or in extreme outdoor conditions.

2.7 Building fabric and services integration:

Passive systems of environmental control were traditionally well expressed and integrated in building forms (ex. wind towers of the Middle East, chimneys in cold climates). Though traditional buildings encapsulate years of trial and error to adapt to a particular region, these buildings must act as precedents, which inform architects but not a solid technique that would impinge on architectural decisions. These buildings occurred in a certain context indicating the availability of certain resources, technologies and social and political ideologies that has changed.[3] This transformation in social, scientific and technological achievements found its roots in the scientific revolution. The scientific revolution from its origins in the Renaissance, reached out to industrial Britain and Evolutionary France, to engage with the practical concerns of everyday life (Maver 1971) argues that the industrial revolution was the first stimulus to drive away the building fabric from its historical symbiosis of dealing with the natural environment. It was unacceptable for the use of buildings to be restricted to certain times of the year or to be dependant on daylight hours. Buildings started to depend heavily on technological

[3] Hassan Fathi's attempt at Gouna to construct a vernacular village (though very successful as a climate modifier envelope) has not succeeded in attracting occupants or replication of the attempt as it required specific skills and time for its construction, more than the currently wide spread use of concrete beam and lentil blocks . Finally the attempt was labelled 'architecture for the rich'.

innovations (such as electrical bulbs by Edison in 1879, and later the fluorescent lamp by (George Westinghouse in 1938) since then more control over the building functions and services continues to drive technology to serve this end.

During the Industrial Revolution, the creation of new modes of production, new patterns of residence (more into the urban areas) and the proliferation of new institutions produced new demands on the form and performance of building fabric. This change affected the energy consumption pattern within the built environment. The advent of electrical power led to the development of improved environmental services. Fans facilitating natural ventilation, compressors for supplying cooling and heating, brought together the air conditioning systems that were created for year round tempering of the indoor thermal environments.

Historically the mass of the structure provided security and protection from climatic extremes, while openings provided light and ventilation. Driven by available technologies the function of security has been partly taken over by electronic control devices while the function of moderating the climate has been taken over by cooling and heating systems, while some of the basic functions of providing lighting and ventilation has well been over ridden by electrical bulbs and air conditioning system.
(Hawkes, 1996:99) argues that it is one of the most marked trends in architecture over the centuries, is to replace the functions of the building fabric by engineering service systems. This profound change in the use and technology of buildings was assimilated into the intellectual and physical fabric of architecture with virtually no visual or stylistic effect. Historically, passive means of regulating the indoor environments like the wind catchers *(malqaf)* integrated in the building fabric. These systems date back to Pharonic times (1300 B.C.) when it first appeared on a painting of Neb Amun's house in his tomb (Figure 23).

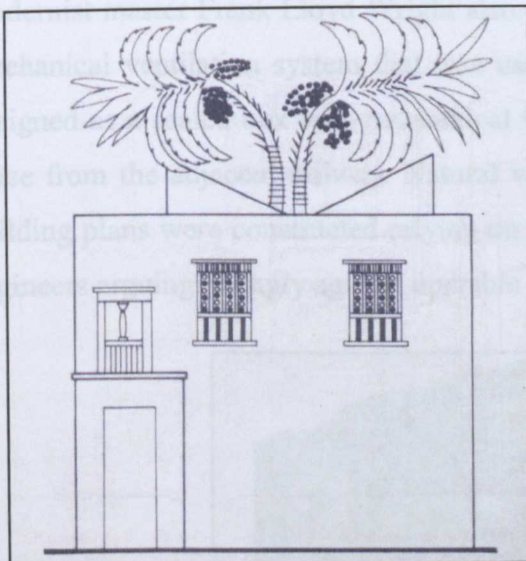


Figure 23: House of Neb Amoun from a painting on his tomb.

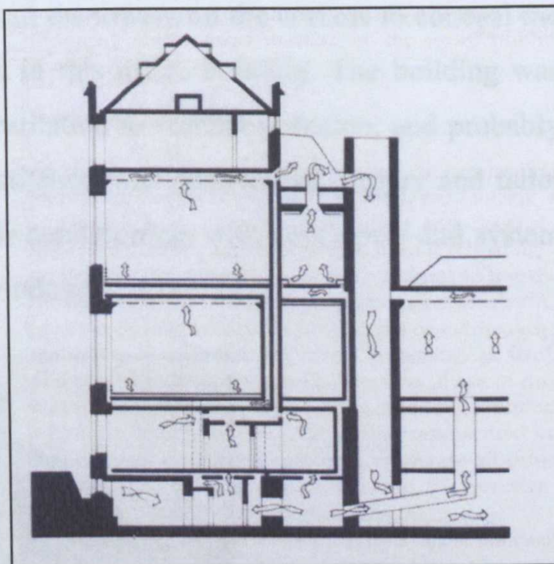


Figure 22: Cross section through old British Parliament Building

Passive systems (or building services in a sense) remained to be integrated into Roman buildings and later on in Islamic architecture and Renaissance architecture in Europe. However the integration of these passive systems as building services utilizing active means of control and aided by technology is not founded till the industrial revolution in Europe.(ex. Fans to extract air from ducts) The old British Parliament House by Sir Charles Barry, in London 1835-52 (Figure 22), incorporated the services system into this early Victorian style building. This was to achieve distribution of fresh, warmed air thorough a network of ducts and flues incorporated within the walls, floors and the roof structures. Also the system acted as an extract for removal of combustion by products, mainly resultant from the use of gas as the only means for artificial lighting after daylight hours.

As a product of the architect's attitude in integrating building technology well into the building fabric, unobtrusive ways of incorporating complex and often bulky systems into the fabric were found. The exterior building envelope played a major role in these strategies, while maintaining the envelope's historical function of dealing with the environment. The Larkin building (Figure 24) an early example of the works of the modernist master Frank Lloyd Wright also used the towers on the corners to conceal the mechanical ventilation system that was used in this office building. The building was designed as a sealed box with mechanical ventilation to combat pollution, and probably noise from the adjacent railway. Natural ventilation was disfavoured, deeper and taller building plans were constructed relying on air-conditioning, with developers and system engineers arguing strongly against operable windows.

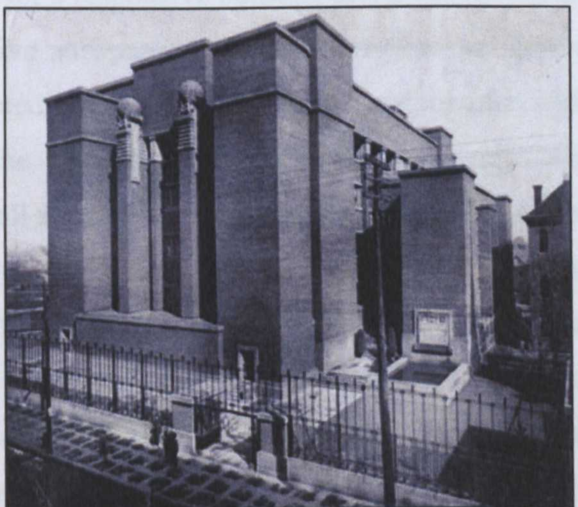


Figure 24: Larkin Building.

Calls in modern movement to dissolve the building facades and fuse it into a transparent filgeree façade aesthetic found their way to realization by advancements in curtain wall construction systems. Due to its thin thickness, the role of the exterior fabric in integrating building services was diminished. Mechanical systems were subordinated, where it becomes totally invisible and uninterrupted within the building fabric but rather sealed by means of false ceilings for its ducts. The bulk of the system would typically be hidden in basements of in service floors.

The post-modernism movement recognized the building systems, this was epitomized in the George Pompido centre in Paris by Renzo Piano and Partners where the building systems although not integrated within the façade were treated as a aesthetic accompaniment to the building's curtain wall.

In response to repetitive oil shocks and increasing environmental concerns, passive architecture has evolved in response to concerns about the implications of excessive dependence on mechanical provision, and related building energy consumption. In the early 80's based on knowledge of passive climatic controls of building, double skin façade and glass covered atriums were used as options for achieving passive architecture. However passive approach cannot solve all problems of climate and control, which endorsed the need for a responsive building fabric depending and requiring technology to integrate both active and passive building services and controls to provide a building façade with enhanced visual amenity, thermal performance while being maintainable and cost effective. The opportunity was seized by many architects and architectural technologists to call for the re-integration *of the system within the building fabric as a design opportunity:* examples of which the active system ductwork is allocated and integrated within the fabric (Guise 1991:70). Passive technologies such as double skin façade and atrium buildings were also emerging as design options that may integrate with the building systems and intelligent controls. These passive envelope technologies expressed the building systems or to decrease its energy consumption. The New parliament building in London

By the start of the 21st century, more acknowledgment of the need to integrate technology in façade construction and building services is founded. Wigginton and Harris (2002) clarify the difference between demanding a passive and a responsive façade. While both façade approaches are built upon an environmental imperative based on considerations of reducing energy consumption while providing indoor comfort, the emphasis is on active and automatic control of the functions performed by the building envelope. This is very different to the conventional passive architectural approach, which prevailed in environmental design of buildings.

2.7.1 Façade design strategies in Cairo:

The main objective in façade design in a hot arid area such as Cairo depends on shading facades from direct solar radiation. Shading systems in this climatic context are used as a selective environmental control strategy that is incorporated within the building fabric to achieve environmental control. Glazed areas are the weakest element in terms of direct solar transmittance into the building interior. Shading systems for facades maybe applied externally, internally or integrated between façade layers. It is essential for buildings to reduce overheating, reduce glare and provide privacy. However from a thermal perspective external shading is more effective than internal solar shading as it prevents direct radiation before it reaches the façade plane (Sinai, 1973). Exterior solar control devices application is considered more advantageous than other shading methods as the heat resulting from re-radiation from the device itself, remains on the outside of the building (Table 3). However exterior shading systems are disadvantageous if the exterior system is made of fabric or even metal louvers are exposed to pollution and weather thus requiring a higher cost for regular cleaning and maintenance. Campagno, (1995:77). However, overhangs and canopies have a seasonal variation in performance and maintenance is a major issue as these systems collect dirt and make window cleaning difficult. In contrast traditional architecture in hot arid climates, where overheating is the main problem used small windows located relatively high in the wall to control ground reflected glare and heat. The traditional device of wooden lattice covered the window completely. But the window apparatus was divided into different apertures, with shading device itself and the glazed panels behind divided for separate functions. The wooden balusters and the interstices varied in characteristics in terms of shape, size and density over the opening (Fathi, 1986). For comfort in hot arid areas reduction of heat takes precedence over air movement. (Saini,1973) To achieve this reduction adequate internal and internal shading must be utilized combined with other measures to reduce intense glare and penetration of dust.

In hot arid areas such as Cairo, traditionally an exclusive environmental building mode was developed in the buildings and outdoor spaces to be protected as much as possible from the intense solar radiation and the hot dusty wind (Koenigsberger et al, 1973: 204). In Cairo, It is observed that in office building facades the common means of providing exterior shading are wooden shutters and sun breakers or brise soleils. It is observed that whenever wooden shutters are used, they are kept shut during the morning hours to exclude the adverse climatic and environmental conditions prevailing during morning occupation hours. Due to the nature of the hostile outdoor conditions in hot arid climate, breezes cannot be used to advantage indoors, unless the air is cooled and dust filtered out. The function of exterior solar shading devices such as shutters and roller blinds are valuable to rooms that are unoccupied during the day as they properly control solar gain but block the view out. The increasing use of glazed areas in buildings in hot areas led to the development of sun louvers or brise soleils (sun breakers). However, in hot arid areas indiscriminate use of sun louvers can have an adverse effect, particularly when the blades are made of heavy materials. This was demonstrated in the High court in Chandigarh (designed by Le Corbusier in India). The efficiency of these heavy concrete louvers is considerably reduced because of their high heat storage capacity. After sunset, the louvers steadily warm the cool night air on its way into the building, thus making it difficult for interiors to cool for daytime comfort. (Sinai, 1973:49).

Table 3: Comparison between external and internal performance of shading systems

Type of shade:	% of heat gain compared to clear glazing un-shaded window
Outside slatted shade, slates set to prevent direct sun falling on glass; light colours	15
Outside commercial bronze shading screen of narrow metal slats,	15
Outside canvas, awning, sides open: dark or medium colour	25
Inside Venetian light colour blinds, slats set to prevent direct sunshine	45
Ditto: white or cream	55
Inside roller shutters fully drawn : dark colour	80

The configuration of the glazing to wall area impacts the quality and quantity of the luminous environment. Baker (1999) advocated that in temperate climates it is recommended to keep glazing window to wall ratios to a minimum of 25% upwards according to glazing type and orientation to provide suitable views and daylight, however ratios above 50% should generally be avoided due to increased risk of overheating. Vartianinent *et al* (2000) simulated four different geographic locations to study window design for daylight optimisation. The study concluded that if lighting requirements are 500 Lux for the area adjacent to the façade then in any geographic location it is possible to provide 90% of the maximum available daylight in that particular location with a window to wall ratio of 25%. The research also indicated that variations in daylight availability in relation to window orientation are kept to a minimum with the 25% WWR.

In Egypt, no regulation found differentiated between an office or residential requirements for daylight or thermal performance requirements. The regulation demands a minimum of 8% of the floor area to be day lit with a minimum width to the opening of $1m^2$. It is notable that this regulation is not concerned with the glazing type used, or effects of over hangs or shading systems. Therefore, the configuration of the façade must be examined in the context of its appropriateness in both physical and psychological contexts.

Current research is emphasizing the need of envelopes to retain an intelligent dynamic filter by using computer controlled devices for selective shading, or movable insulating systems or building materials that change their properties in response to changes in the environment. However the utilization of such systems with their fine tuning and high maintenance requirements is debatable in hot arid areas where sandstorm prevail and their fine particles may block the mechanisms rendering them ineffective. Retractable louvers are still considered an expensive technology; access to motor systems for these louvers has to be widely available with possible interruption to occupants. (Littlefair, 1999).

2.7.2 Glazing Systems:

Clear glazing offered the most transparent look for a building with the highest performance of daylight transmittance but also with the highest heat loss and gain potential.

For centuries clear glazing panes remained the only option for windows. The economic push towards saving energy consumption in buildings is a main driver behind advances in research and manufacturing technologies of glazing systems. A wide range of glazing types using different technologies has been utilized in temperate climates where glazed areas are looked upon as a reason for heat loss. To reflect indoors energy consumed on heating buildings, glazing options range from using air spaces, gas filled insulating glass, low emissivity coatings and aerogels. To further prevent heat loss through windows cavities between window panes have been ventilated mechanically with upwards or downward flows examples Museum if arts and crafts Frankfurt (1979-84) by Richard Meier and Lloyds Insurance company in London (1978-86) by Foster and Partners and the New parliament building in London 'Portcullis House' By John Hopkins and partners (1989-2000). For hot climates, the thermal and daylight requirements are different and a different strategy is required to meet occupants' demands. Little research has so far been carried out on thermally insulating fillings; vented air spaces, therefore blinds and louver systems with infrared- reflecting films are the available options. The following section will review options currently available for hot arid regions.

As glazing areas determines levels of light and heat gains or losses, even in moderate climates, in Office buildings, heat losses through building facades are becoming less significant. This is attributed in part due advances in façade technologies such as advanced glazing and insulation materials leading to lower heat loss coefficient, and in part to the internal heat generation due to equipment, occupants and lighting. These particular aspects become an extra burden on cooling systems in hot arid climates, where the technical requirements of a façade require providing daylight and reflecting the intense solar radiation. In hot arid areas it is common knowledge that clear glazing needs to be complemented with shading strategies to achieve a climatic responsive facade. Campagno (1999), identifies passive and active measures to improve the glazing performance. Passive uncontrollable measures is characterized by fixed properties such as surface coatings these measures include changing the glass surface properties, adding inter-layers between glass panes, combining glazing with additional solar and insulation constructed layers such as double skin facades.

2.7.2.1 Glazing types and options for hot arid climates:

While providing natural light, sunlight and a view out, the main requirement for the use of glass in hot climates is to provide high levels of solar control to minimize solar heat gains and air-conditioning loads. Glazing areas design is also required to prevent provide control of glare arising from reflections from the ground, surrounding buildings and bright areas of the sky.

These technologies maybe classified into clear glazing with combined shading systems, absorbing glazing, reflective coatings, spectrally selective coatings, and recently what is termed as smart windows which combines the previous glazing types with the building services systems or is capable of switching its properties according to season.

Body Tinted Glazing:

This is clear glazing with tinted coatings to absorb solar gains. Part of the heat continues to pass through tinted glazing by conduction and radiation. This type of glass reflects only a small percentage of light. Grey and bronze tinted windows reduce the penetration of both light and heat into buildings in equal amounts. Green and blue tinted offer greater penetration of visible light and slightly reduced heat transfer compared with other colours. In hot climates, tinted glass should be avoided as it absorbs more light than heat (DOE report). Grey tinted glass, achieved by adding Nickel oxide, and bronze-tinted glass, produced by adding Selenium are used to reduce glare which makes their use more suitable for the clear sky conditions prevailing in hot arid areas. However, the addition of metal oxides to the base glass leads to a stronger tint which produces a higher ratio of absorption and a resulting increase in the temperature of the glass which in turn starts to re-radiate the absorbed heat into the room leading to increases in cooling loads of buildings. The utilization of tinted glazing in hot arid areas was the only available option to reduce cooling loads in buildings till the glass industry provided advanced glazing types such as reflective and spectrally selective glazing types.

Reflective glazing:

Developed in the 1960's, reflective glazing was effectively developed for hot regions. The coatings were, in performance terms, essentially radiation shields, reflecting away unwanted solar radiation. Visually from the outside they were called 'mirror glass buildings'. Mirror making had a long stand in history mastered by the Venetians, and continuously placing more rigorous demands on the glass industry to process better glass sheets of improved flatness and purity as only the best quality of glass can be coated with silver to produce a mirror.

During the last quarter of the twentieth century manufacturing performance improvements led to development and enabling the application of thinner reflective coatings to glass, to improve their thermal efficiency as well as reduce sharp reflections of light to the outside.

The advantages of reflective glazing over tinted may be summarized as

- Greater production flexibility and performance range than body tinted.
- Higher solar and visible light attenuation
- A range of colour appearances in transmission and reflection (Button et al, 1993:165)

In hot arid regions, effective solar control is achieved by applying surface coatings increasing the reflective properties of the glass surface leading to a reduction in the level of transmission of energy into the space. Reflective coatings maybe applied to both clear and tinted glazing. As tinted glazing has higher absorption properties, lower g-factors maybe achieved (Campagno, 1999:33). Hard surface coatings are applied to heated float glass by pouring the coating material in liquid or powder form then fired. As a result chemically resistant and durable hard layer of 100-400 nm thick is formed on one side of the glass sheet. To attain its reflective qualities metal oxides such as titanium, chrome, nickel and iron are used. Glass panes with hard coatings can be used in single glazing.

Soft reflective coatings are applied to glass by immersing the sheets into chemical solutions, and then firing the sheets, the coatings are generally on both sides, in the near infra red coatings are more active reflecting than absorbing (Campagno, 1999).
The reflectance of most types of glazing increases as the viewing angle departs from the normal; the more the oblique angle, the stronger the reflection and the more obscured the view through any glass. Reflections of the sunlight from the glass can never be as bright as direct sunlight, but where reflections are perceived to be problematic, computational predictions maybe applied to establish the reflected sunlight from buildings. Where it is important to minimize reflections, an 'anti-reflection coating' maybe applied which is a thin transparent coating maybe applied with a thickness comparable with one quarters of the wavelength being controlled. (Button, 1993:61)

Spectrally selective glazing:

By controlling solar heat gains in summer, preventing loss of interior heat in winter, allowing occupants to reduce electric use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. This technology is most effective for residential and non-residential facilities that have large cooling loads, high utility rates, poorly performing existing glazing (such as single pane clear glass or dark tinted glass) (DOE/EE)-0173

Spectrally Selective Glazing is considered as the next generation of Low-e technologies. These coatings filter out from 40-70% of the heat transmitted normally through clear glazing, while allowing visible wave lengths to be transmitted.

2.7.3 Building Fabric Thermal performance in Cairo;

Simulation studies of single building skins, conducted on hot arid areas differed in quantifying the façade's impact on the operational energy in hot arid areas ranging between 40% (ElKadi, et al, 1999), between 60-70% (Al-Mujahid 1995). However the effect of façade configurations on hot arid areas is significant.

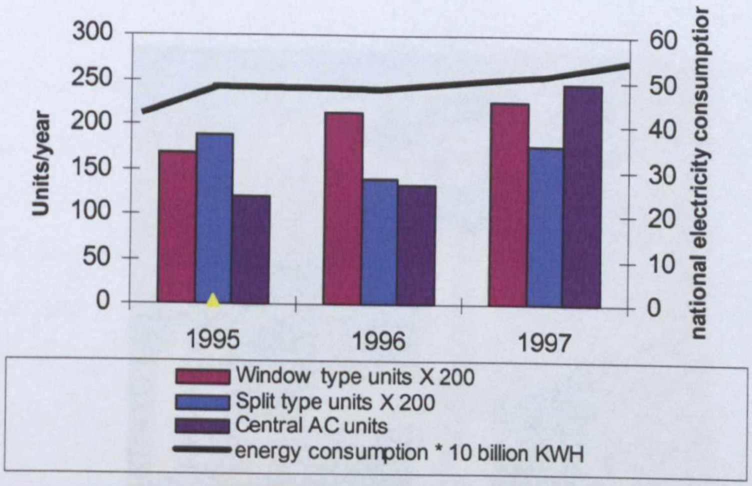


Figure 25: relation between increases in air-conditioning unit sales and national energy consumption

In Cairo, it is an easily observed phenomenon that building facades whether residential or public are increasingly failing their historical role as climatic moderators, and their ability to facilitate a well-controlled and thermally comfortable indoor environment. Split air conditioning units are increasing in number, perforating existing facades. In 1998 the Egyptian Code for building envelope for thermal performance was issued as an effort to integrate between architectural design and thermal performance to reduce dependence on cooling systems. Figure , indicates the relation between the increase in electricity demand and the increase in use of these cooling systems

Historically, the limited scope of passive cooling systems led to insights of constructing the building facades with various layers to create unheated or un-cooled buffer spaces around rooms for human occupation. In hot arid areas this was demonstrated in balconies and arcades in front of buildings and in court houses, the main function of these spaces was to provide a space where air temperature would be that of shade and not affected by the solar direct radiation (sol-air temperature).

Shading systems that were used in office building facades such as wooden shades or even fixed concrete louvers were gradually being removed from existing facades. In some cases the fixed shading systems were used as structural systems to support air conditioning units (Figure 26).

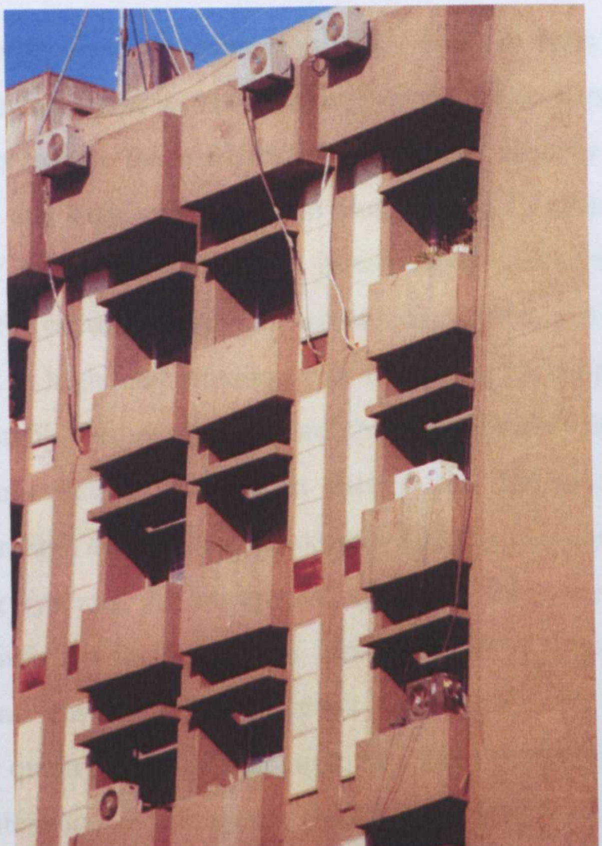


Figure 26: Use of shading systems as support for air conditioning systems.

The explanation of the failure of these shading systems on facades, that led to there removal from several building facades in Cairo in analysed by (Fathi, 1986), that though the wooden Venetian blinds (shutters) are capable of intercepting the direct solar radiation, they obstruct the view to the outside, considerably dimming light reaching the interior. Though these shutters would not obscure the breeze, natural ventilation coming through them is deemed unsatisfactory as they direct the breeze upwards above occupants' head levels. If they are made of metal then absorption of the direct radiation takes place at the shading device level, is absorbed then re-radiated into the room as heat. The modern movement also introduced the Brise-soleil or sun breakers used to shield entire facades of glazed walls. The concept itself was used to provide outside views, while effectively reducing heat gains from the façade. The result was a view slashed by large dark stripes interspersed by offensive glare.

However, this increase in demand on split / window units that is recorded as a phenomena in developing countries has an energy consumption penalty. Air conditioning has been assumed to replace the need for climate design features in buildings creating poor thermal design and high energy use. In Hong Kong, facades are experiencing the same phenomena of perforating facades to install cheap split/window air conditioning units. In comparing the central and split air conditioning systems in Hong Kong (Yang *et al*, 2001), argue that in high load buildings (such as office buildings), the perceived idea that split units consume less energy and are cheaper to install than central systems is mistaken. Split units consume 35% higher energy than that of a central conditioning system. Therefore, in high cooling load dominated building it is energy efficient to install central conditioning systems. An occupants' survey in the same study, indicated that occupants were satisfied with the ease of installation of split units, and simplicity in metering the bills and less space for equipment. Dislikes for split systems were towards less control over air quality and a shorter equipment life cycle, higher levels of generated noise, higher maintenance requirements, and higher temperature fluctuations in the rooms.

Split/ window type conditioning is observed to increase noise levels in Cairo. Its cooling efficiency in a highly urbanized city is debated. (Bojic et al 2001) studied the airflow and temperatures outside a high-rise residential building due to heat rejection by its split type air-conditioners. The results indicated that condenser units suffer more when they are placed inside taller recessed space. As heat rejected from condensers rises upwards in a hot air stream, and these units would draw less air at an elevated temperature, and therefore become less energy efficient and de-rated in output capacity and sometime have interrupted operation. There is also the effect of the increased utilizations of window type and split units in high cooling loads buildings and the increase in noise levels and the urban heat island. Therefore, in public buildings it is beneficial not only to look at the initial costs of cheap split or window systems but rather at the long term implications. The implications of these cooling strategies on degrading facades are evident with office buildings in Cairo using hundreds of units on each façade. There is also the emerging problem of condensation water from these systems that degrade the façade finishes. A solution was found for this problem in the Hezb Building by installing pipes on the façade to collect condensation water, an arguable solution on its effect on building aesthetics, and feasibility of façade maintenance.

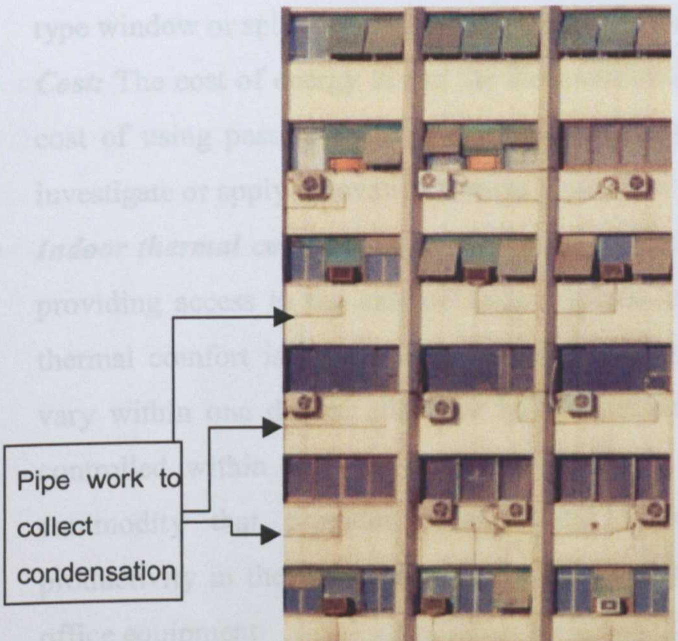


Figure 28: pipe work and electrical connections on the facade

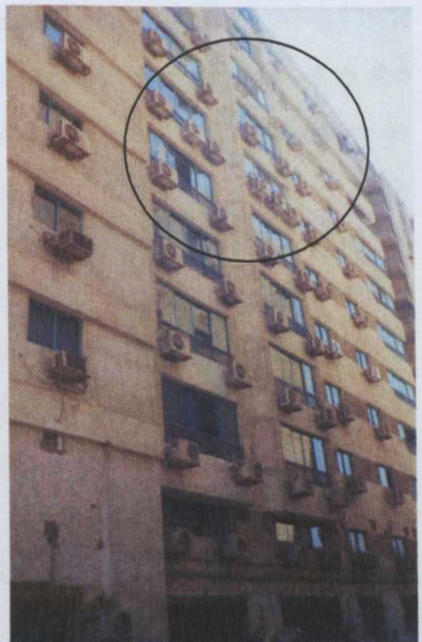


Figure 27: Ministry of Environment Affairs Building in Maadi, Cairo. Excessive use of conditioning units

The recently occupied Ministry of Environmental Affairs building in (1998), witnessed the same phenomenon of piercing the façade for air-conditioning units, not only deteriorating the aesthetics of the façade but relying questionably on energy resources (Figure 27).

The reason behind dependency and utilization of air-conditioning systems has witnessed an increase in developing countries among which Egypt is considered.

The utilization of air conditioning systems may be attributed to:

- ***Site utilization:*** allows for dense site coverage and decrease of the need for wind wells, courtyards or covered atriums
- ***High market penetration*** of sophisticated HVAC systems has progressed rapidly at the expense of less energy active systems.
- As the prices for air conditioning units fell and their efficiency increased. Most of the originally designed for natural ventilation office space have adopted the residential type window or split air conditioning units into their building fabric.
- ***Cost:*** The cost of energy to run the air-conditioning systems is low compared to the cost of using passive systems (ex.Photovoltaics), hence there is little incentive to investigate or apply innovative passive systems or passive design in buildings
- ***Indoor thermal comfort:*** the use of air conditioning decreases design constraints on providing access to the external environments and passive control methods. While thermal comfort is provided by using mechanical cooling or heating controlled to vary within one degree above or below comfort temperatures. While humidity is controlled within 5% of the desired level. In office buildings this is seen as a commodity that provides comfort and reduces absenteeism and increases productivity in the workplace while providing thermal control for sensitive IT and office equipment

In Cairo, to avoid high energy consumption, Central temperature control has been used to prevent users from adjusting their own thermostats. Windows were sealed to prevent tampering. In this case less air is drawn in, thus raising concerns towards indoor air quality and hygiene.

2.7.4 The need for air conditioning

Besides the many advantages of natural ventilation, it has one disadvantage. Natural ventilation is not always energy efficient. In hot arid climates, natural ventilation admits the unmodified atmosphere to the interior. When a building is cross-ventilated during the daytime the temperature of the indoor air and surfaces closely follow the ambient temperature. Therefore, it is only possible to achieve comfort by daytime ventilation only when indoor comfort can be experienced at the outdoor air temperature (Givoni,1994). During summer in a hot dry climate it is both desirable and possible to lower the indoor temperature significantly below the outdoor level during the daytime hours by minimizing the heat gain from the outdoor air. To this end the building should be compact, the surface area of its external envelope should be as small as possible to minimize the heat flow inside the building. The ventilation rate should be kept to a minimum required for health.

To understand the weather profile of Cairo and its effect on indoor thermal comfort, an enthalpy graph using both wet and dry bulb temperatures was used, indicating average annual ambient enthalpy conditions plotted against maximum and minimum enthalpy conditions recommended by both CIBSE AND ASHRAE standards for indoor thermal comfort for office occupancy.

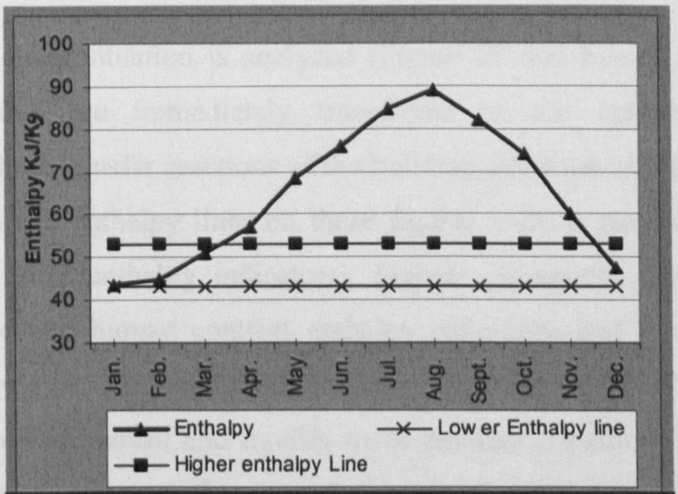


Figure 29: Annual enthalpy conditions

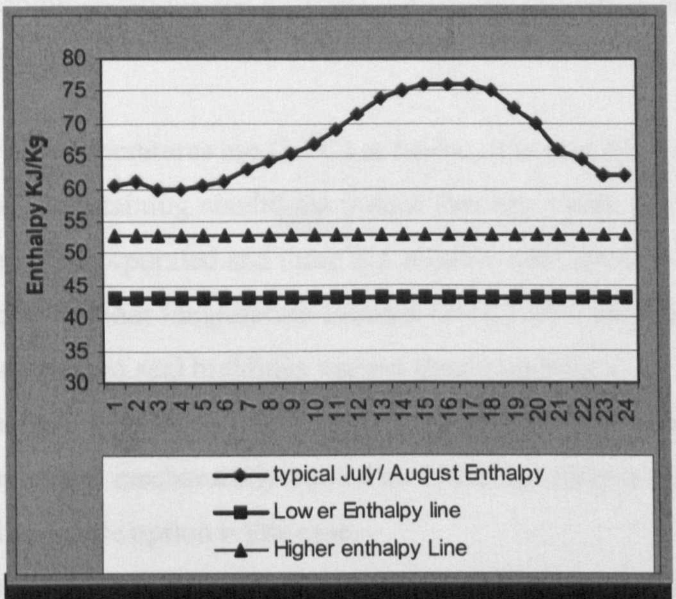


Figure 30: Enthalpy conditions in July/August

A hypothetical situation is analyzed (Figure 29 and Figure 30) where outdoor climatic conditions are immediately transferred to the indoor conditions, thus disregarding the heat transfer reactions of the building envelope as well as internal gains. The upper and lower enthalpy lines on these figures indicate maximum and minimum comfort levels (using enthalpy indicators). Figure , illustrates that ambient weather conditions are beyond human comfort enthalpy conditions and therefore in an office environment may need to be excluded during building occupied periods. Figure , highlights the need to control and modify these ambient conditions to provide thermal comfort indoors in summer months.

Cairo similar to other urban centres experiences the 'heat island effect' where the concentration of heat sources (air-conditioners, car exhaust, people and their activities) alongside the changes of surface (due to buildings and street coverings) intensify solar radiation and its reflections which increases the Sol-Air temperature. These effects combined with indoor thermal gains would accentuate the need for thermal control strategies to provide building occupants' with thermal comfort.

General recommendations for building envelopes regulating the climatic effects are:(Stein 2000: 295)

- When outdoor air temperatures are (30^0C) or below, it is possible to cool buildings by simple ventilation, maintaining conditions indoor that are within the 'comfort zone', if natural ventilation is incorporated and there is a reliable wind speed.
- In climates where outdoor temperature exceeds (30^0C) for a large number of working day hours, it is practical to seal buildings against these conditions.
- In outdoor conditions between (13^0C -20^0C) outdoor air is cool enough to be used instead of or supplement mechanically cooled air if the humidity is sufficiently low, and passive cooling is a viable option n this case.
- However these recommendations are general and only dependant on the climatic variables while the effect of indoor gains is excluded.

The design and application of passive cooling systems is often confused with appropriate architectural design for hot regions (Givoni, 1994). Any building is heated up during the day, and cools down during the night as result of heat loss to the outdoor air by convection and of radiant loss to the sky. The daytime heating and night cooling result in an indoor average temperature that is above the outdoor air temperature average, owing to solar radiation that is absorbed in the building's envelope and penetrates through the windows. Thus in reality, even if the windows are effectively shaded and the envelope has a reflective (white or light) colour, the indoor average would be above the outdoor average, due to unavoidable energy absorption in the envelope. The overall elevation of indoor average temperature caused by the direct and indirect solar gain is referred to as the 'sol-air temperature elevation' Indoor temperature is further elevated by occupants, equipment and lighting systems. From the thermal comfort point of view, in the context of cooling dominated buildings, bioclimatic design can only minimize the sol-air elevation. Any lowering of the indoor average below the outdoor level requires the input of cooling energy.

2.8 Summary:

This chapter reviewed the climatic, geographic and historical evolution of Cairo to understand the wider context that affects the location and façade configurations of office buildings in Cairo. The chapter highlighted the various forces underpinning office building façade construction and the related operational energy consumed

- A review of Cairo's geographical location and the socio-political factors behind its urban evolution indicated the reasons behind concentration of office buildings in its CBD and in the new urban settlements of Maadi, Nasr city and parts of Heliopolis.
- The hot arid climatic profile of Cairo dictates façade configurations that are capable of shielding the building against the direct solar radiation. Uncomfortable warm air temperatures prevail during office building occupation hours during the extended summer month period from May till October. Compounded by the high indoor gain levels, natural ventilation is difficult in summer month.
- Modernization of Cairo and industrialization of the city brought in is wake an increase in the urban densities, transport emission problems that along side the natural weather profile led to the need to exclude the outdoor environment. The harsh climatic profile with sand dust storms in addition to poor air quality in Cairo led to changes in the façade function as a selective environmental filter to a climatic and environmental exclusive layer.
- The exclusive mode depends on mechanical systems to achieve thermal comfort. The increase in dependence on mechanical systems is associated with an unaccounted for increase in energy consumption.
- The haphazard puncturing of facades for air conditioning systems combined by the environmental and climatic wearing factors and a long period of neglect necessitates façade refurbishment in Cairo.
- Façade refurbishment is an opportunity to re-integrate the façade as an environmentally selective system, that reduces building energy consumption and responds to occupants' needs and expectations.

- Building facades refurbishment to integrate energy conscious measures (passive or hybrid systems) may decrease the dependency of the built environment on generated energy.

Appendix 1: Chronological Order.

640 A.D. Arab Conquest of Egypt.

642 A.D. Foundation of Fustat by Amr ibn al- As

661 A.D. Start of the Ummayyad Caliphate.

749 Start of the Abbasaid Chaliphate.

751 Foundation of el-Askar.

868-884 Reign of Ahmed ibn Tulun

969 Fatimid Conquest and foundation of El-Qahira.

1163 Nur al Din sends Shrikuh into Egypt with Saladin.

1168 Burning of Fustat.

1174-1193 Reign of Saladin.

1250 Regency of Shgaret al-Durr, First Mamluk Sutana.

1517 Defeat of Mamluks by Ottmans.

1798-1801 Napoleonic Expidition in Egypt.

1805-1848 Reign of Muhammad Ali.

1848 Reign of Ibrahim Pasha.

1863-1879 Reign of Khedive Isma'il

1882 British occupation of Egypt.

1936 Egypt's independence.

1952 Officers Revolution, and Gamal Abel Nasser appointed President.

1970 Sadat becomes President after Nasser's sudden death.

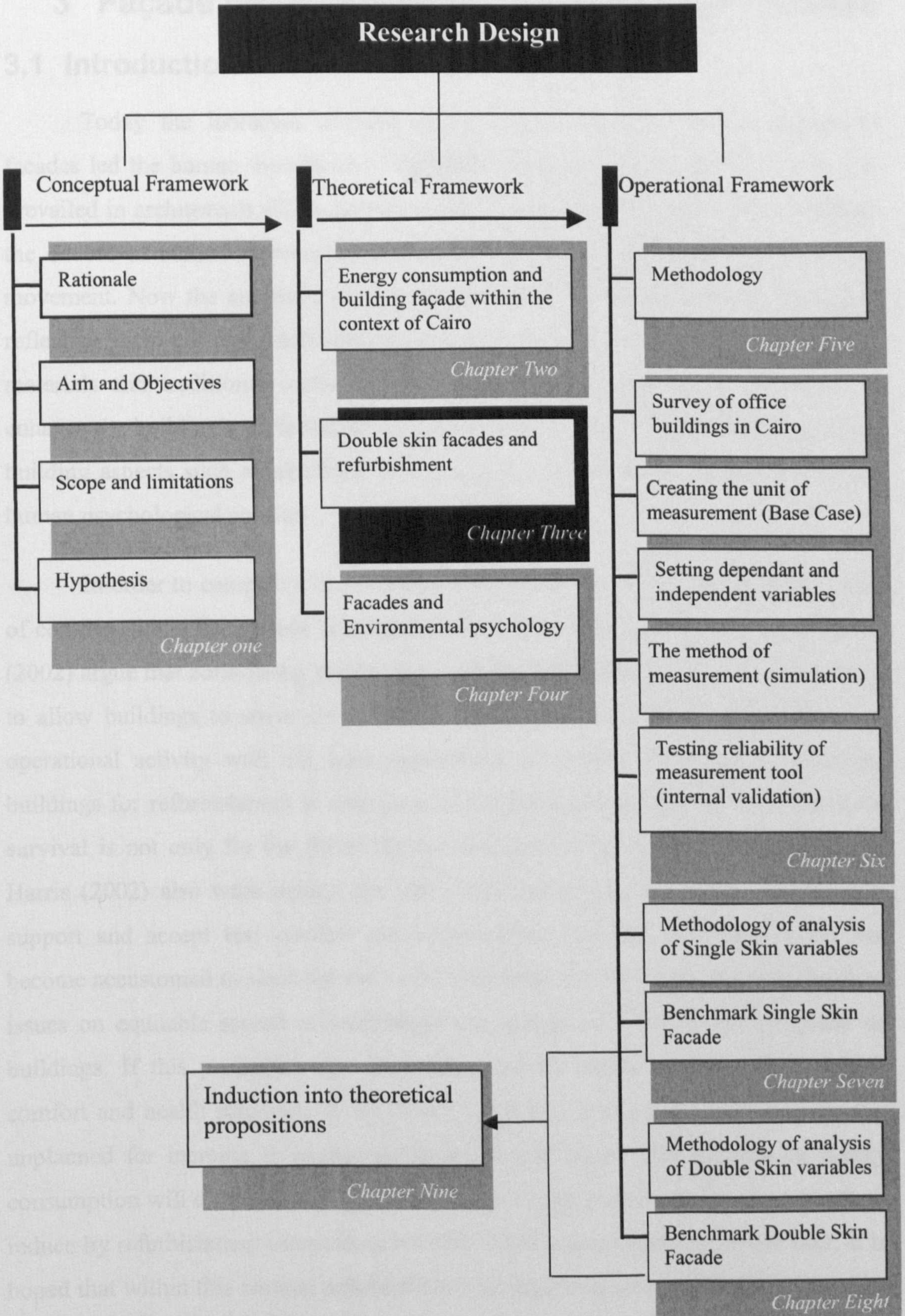
1981 Assassination of Sadat.

1981- Hosny Mubark becomes president.

Chapter Three: Double Skin Facades and Refurbishment

Key Concepts

3.1 Introduction
3.2 Definition of a façade
3.3.The façade as a climate-environment moderator
3.4 Energy conscious refurbishment of Buildings
3.5 The integrated Energy conscious refurbishment strategy
3.6 Double Skin facades as a façade refurbishment option
3.7 Case studies of double skin facades in refurbishment



Chapter Three: Double Skin facades and Refurbishment

3 Façade Refurbishment and Double Skin Facades

3.1 Introduction:

Today the increased demand for intelligent and dynamically responsive facades led the human thought away from the exaggerated cultural expressions that prevailed in architecture till the baroque ages, and also away from the other extreme, the devoid of culture representations, the climate excluding facade of the modern movement. Now the emphasis is on a façade that is climatically sensitive, sensibly reflecting local culture, while integrating vernacular environmental solutions, local materials and traditional crafts with new materials and innovative techniques to enhance the building's performance on various levels. These levels cover multilateral building aspects such as structural safety, energy consciousness, sustainability, and human psychological comfort.

In order to compete with the desirability of new buildings and their provision of comfort, the existing stock is considered for refurbishment. Wigginton and Harris (2002) argue that considering buildings for refurbishment stems from a consciousness to allow buildings to strive for a state in which they were at the highest level of operational activity with the least expenditure on energy. Therefore, considering buildings for refurbishment is analogous to the biological system of evolution were survival is not only for the fittest but the non-survival of the unfit. Wigginton and Harris (2002) also warn against the naïve assumption that developing nations will support and accept less comfort and commodities than the developed world has become accustomed to since the end of the nineteenth century. This argument leads to issues on equitable spread of technology and quality of provision to occupants of buildings. If this prediction that developing nations would require similar indoor comfort and health standards to the developed world is true, then an inevitable and unplanned for increase in energy consumption will arise. This increase in energy consumption will dictate not only an increase in energy production but on methods to reduce by refurbishment the existing building stock consumption as an end user. It is hoped that within this context refurbishment for improved energy efficiency becomes a major topic on the refurbishment agenda

3.2 Definition of a façade:

The Concise Oxford dictionary (Pearsall 1999) defines a 'Façade' as *'the face of the building especially its principal front, or a deceptive outward appearance'*. The definition looks at the building façade as merely a layer covering a building interior that may or may not present its function but rather is intended to project a certain image.

From an energy exchange perspective the façade is defined as: 'not merely the two dimensional surface of exterior elements that separate conditioned and unconditioned space, but a transition space affecting a semi-exterior zone where thermal energy may be transferred to or from the exterior, to conditioned or unconditioned space' (ASHRAE, 1999). The façade components deal with both interior and exterior zones interactively. The facade components are classified by their energy exchange function as a connector, a filter, and a barrier or switch (Norberg-Schulz 1965). A connector as a means to establish direct connection between indoors and outdoors, a filter to provide controlled connection to ambient environmental conditions or select certain ambient effects such as shading devices, a barrier to unwanted climatic conditions, a switch as windows and doors are controlled to act as the previous three elements at the will of occupants. However, the previous definitions still dealt with the façade as a layer. This definition changed during the 1990's as (Lawton,1992) draws attention that even a single skin façade is composed of a series of barriers separating an indoor and outdoor environment. It is subject to driving forces caused by differences between indoor and outdoor environmental conditions. *The energy driving forces* depends on differences in conditions related to atmospheric pressure, temperatures, and moisture conditions between the two environments concerned.

The realization that a building façade deals with the climate while in integration to the building systems and occupants is found in (Stein, 2000:191) stating that:

'A building skin relating to climate while responding to conflicting needs for heating, cooling, ventilation and daylight, where internal loads, zoning and scheduling of functioning hours within the building must be considered as they shift the appropriate design strategies considered for both the façade and the supporting systems'.

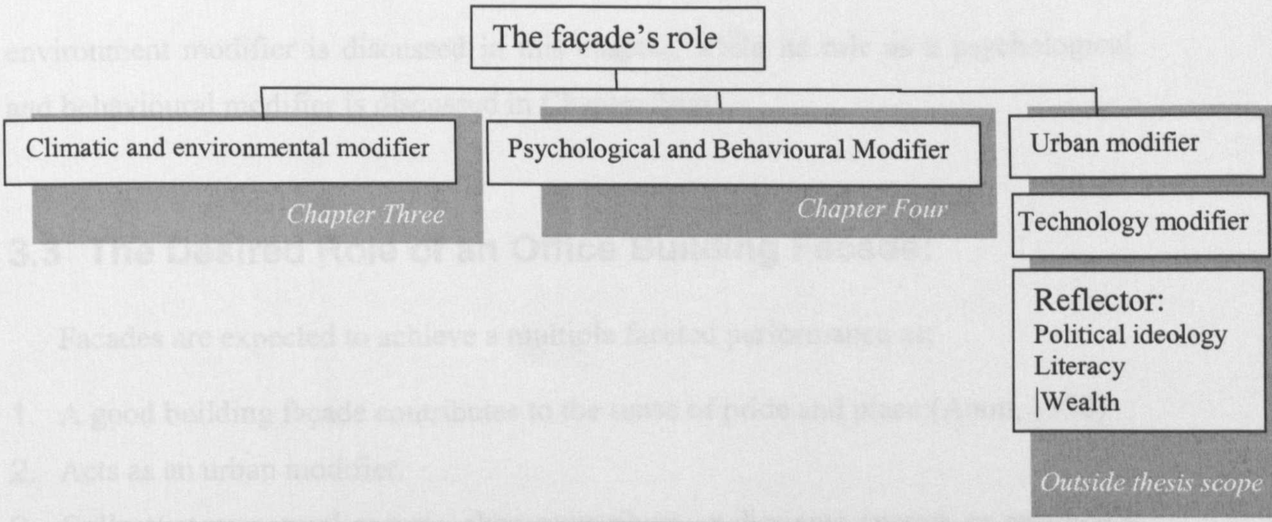


Figure 1: The facade's role

(Wigginton and Harris 2002) draw on the analogy of the building envelope with the body skin, as both are called upon to perform a multitude of simultaneous functions in a relatively thin dimension. These functions can be energy related or non-energy related. A building envelope therefore is a complex system that influences the building energy performance.

The definition of a façade used in this thesis is based on the previous definitions. It is defined as not merely a layer but a holistic interactive system. It is an interactive system used in various modes to connect or separate the external climate or environment or both collectively. The façade as an interactive system is not a stand alone system but acts in integration with building systems to deliver occupants comfort and increase productivity while holistically integrating in its design psychological, socio-cultural, and economic dimensions.

From a psychological point of view, occupants' satisfaction with buildings both externally and internally is a key to building success. It is argued in this thesis that external satisfaction with a building is dependent on the role of the façade as a symbolic and cultural message, while internal satisfaction with the façade configuration incorporates both its physical performance as well as psychological expectations. The role of the façade (Figure1), is expressed by its architectural configuration, which in turn has a direct effect on building energy consumption. In this context, seeking the goal of reducing energy consumption must rely on understanding the role of façade as a holistic system. The facade's role as a climate-environment modifier is discussed in this chapter, while its role as a psychological and behavioural modifier is discussed in Chapter Four .

3.3 The Desired Role of an Office Building Facade:

Facades are expected to achieve a multiple faceted performance as;

1. A good building façade contributes to the sense of pride and place;(Anon, 1990)
2. Acts as an urban modifier.
3. Collect/ store natural energy., then redistribute or dissipate energy, or regulate it throughout the building; (Battle & McCarthy, 1992)
4. Mimic well known old heavy massed facades in their thermal performance and durability, but with light weight materials;
5. Act as a filter, controlling flows of water, noise propagation, natural ventilation, views, heat, fire, pollution, and provides security,
6. Reflect advances in building materials technologies and state of the art construction methods, to reflect institutional wealth;
7. Facades being of dynamic thermal performance, with glazing materials and opaque surfaces acting as an integrated building skin, but without using intrusive technology, sophisticated or decreased occupants' control. 'The more high technology around us, the more the needs for human touch'; (Naisbet, 2000)
8. Does not increase fire risks on the building or its occupants;
9. Being a dynamic multi-functional enclosure;
10. Being multi-layer, each layer, playing a different role, such as reflecting heat, water proofing;
11. Act as intelligent skin in the context of its ability to mimic human skin while responding predictably to environmental variations and stresses; (Harris et al, 1998)
12. Mimic human and animal skins in a self-healing manner, in a way that maintenance and repair would be an easily ongoing process and not a once off major necessity after a lot of damage has already been inflicted; (Alexandros 1996)
13. Preserve monumentality and detailing. Traditionally monumental architecture was linked to a profligate attitude to resources. (Hyde, 2000) Refurbishment of office

buildings façade may be seen as conserving their monumentality while using energy conscious design attitudes.

14. Integrate technologies to help the building in generating part or all of its energy from renewable resources (i.e. photovoltaics and solar cells)

Ideally, a perfect façade would interactively respond to all the previous criteria. However, this would require a multi-disciplinary team. In this thesis, due to the context specific setting of Cairo as an urban environment in a hot arid area, two aspects are focused upon in detail, the role of the façade as a climate-environment moderator and the role of the façade as a psychological manipulator.

3.4 The façade as a Climate- environment moderator:

Throughout history, facades, as an integral part of a building's envelope, redeemed their primary function to shelter from climate and provide safety from the wider subset of unpredicted climatic conditions. Buildings were designed to sensitively adapt to their environments (such as the Inuit Igloo in the cold north, setting different functional rooms around a shaded court in hot arid areas, to massive structures with fireplaces in temperate climates). These prototypes with their low dependence on fossil fuel were energy conscious and offered climate adaptive envelopes (Jones 1998) and (Duffy, 1995). Architecture was aspired to go with the natural systems rather than over-riding it, as buildings were to better adapt to climates and resources of the region.

The earliest extensive account of the role of the façade as an environmental moderator dates back to Vitruvius ten books on architecture (20-30B.C.) in his tri-partite model describing the role of architecture, climate and comfort, where the architecture of the building is claimed to amend by art what nature would mar or exaggerate (Rowland and Howe ed., 1999)

In responding to the climatic constraints of hot arid areas, building facades have gained certain easily observed forms such as shaded openings, projection of overhangs and balconies in hot arid climates.

Where in Europe and the States the change of the facades role as a climatic moderator to an environmental separator dates back to late nineteenth century The industrialization adverse effect on urban atmosphere was manifested in extremely polluted environments by the products of combustion, especially from coal, for industrial manufacturing. Engineers and architects of the time began investigating ways of producing cleaner air inside their buildings. The discovery of petroleum and its concentrated energy content with the possibility of cheap delivered electricity further encouraged architects to drive architecture away from its environment, and depend on mechanical systems. With the discovery of air conditioning in the 1930 this trend was pushed further. Due to interchange of cultural ideologies and trends of global economic exchanges between industrializing countries and Europe and the United States, both the façade expression and function experienced changes during the previous century.

The development of highly mechanical serviced buildings alongside advancements in glazing technology gave rise to the universally sealed and glazed office block by the modernist master Mies Van de Rohe in the Seagram office building in 1958. Seagram building was criticized as a mechanical system wrapped in a membrane (Roth 1993:129). The sealed glazed office blocks became standard requirements all over the world, particularly for multinational companies. Their construction depended on collaborative teamwork between architects, mechanical and construction engineers, cladding suppliers, in the twentieth century

The environment exclusive façade of the modernist gave rise to increased occupant discomfort, indoor diseases, and a dangerous escalation to the dependency on fossil fuels to feed all the mechanical building services. This severe environmental degradation led to encouragement of climate sensitive design.

In 1960s (Olgyay 1963) regenerated the role of the façade as an environmental moderator after its functional demise under the modernist movement. Olgyay returned to the basic Vitruvian tri-partite of 'Commodity, firmness and Delight' but extended the original Vitruvian model functions of dealing with Climate, comfort, and architecture to include technology. Technology was then regarded as an assistant for the building fabric and its environmental role. Olgyay, may be considered the first advocate to what would be called later 'Bioclimatic architecture'. Bioclimatic architecture is defined by its reliance on ambient energy, local and individual control over environment while reducing fuel utilization.

During the late 1980's, the greenhouse effect was linked to the increase in carbon dioxide emissions not from the industrial sector alone but from the built environment as a whole. The heavy utilization of energy to attain user's comfort indicated that carbon dioxide emissions arising from the profligate and inefficient use of energy in buildings was greater in conventional air-conditioned office buildings than bioclimatic offices. A conventional air-conditioned office produces five to six times the carbon dioxide of a well-designed bioclimatic office (Jones 1998). The realization that the difference between the totally glazed office building and other prototypes of vernacular architecture was not simply the contrast between an advanced technological architecture and primitive building, but also the contrast between the profligate use of energy to attain occupant's comfort. (Wigginton and Harris 2002) argue that bioclimatic architecture advocated an architecture that could attain user's comfort without recourse to energy consumption, which proved to be an idealistic scenario that could not be achieved in reality.

Intelligent buildings were introduced in early seventies as a concept and in practice due to the phenomenal advances in computer technology, solar cell and silicone wafers, as well as glazing technologies. It was then believed that a single computer could efficiently manage and integrate the building services and systems, solar technologies and silicone wafers may be used to generate energy from facades, while advanced glazing systems maybe used to control heat gain or loss as well as daylight performance. The polyvalent wall was introduced to integrate these technologies to develop a multi layer façade consisting of several multi performance glazing which would dynamically regulate the energy flow from outside to inside and vice versa (Davies 1981) that would change its appearance in dealing with climatic variables with analogies to a chameleon skin and act as a polyvalent wall. (Davies 1981) quoted: *'I propose that the average building should know how it feels. Such a building is an intelligent building which is aware of itself; aware of the energy falling on the façade; aware of the energy coming through the façade; aware of the people inside the building and what their needs are'*

The intelligent building was defined as (Robathan, 1989) 'the one that creates an environment that maximizes the efficiency of the occupants of the building, while at the same time allowing effective management of resources with minimum life-time costing.

By 2020, the industry envisions building envelopes that are net producers of energy, with movable walls and rooms that adapt to changing needs and environmental factors. The 2020 building envelope's intelligent features will adjust the interior climate based on the weather and provide naturally derived lighting and ventilation, enhancing overall comfort and occupant health (http://www.energy.gov/HQPress/releases01/maypr/pr01071.htm.)

In conclusion, facades as a climate modifier will have to adopt a hybrid interaction between climate and technology to sustain the indoor environment.

In this context, it is important to note that the role of the façade is complex and energy savings is but one aspect of this complicated relationship. Occupants' satisfaction with the building both externally and internally is a key to building success. In this context, seeking the goal of reducing energy consumption must rely on understanding occupants' demands and expectations from a building façade.

From a thermal point of view, achieving a bioclimatic façade depends on analysing "passive" responses of vernacular architecture to the local environmental conditions. As they represent a treasury of knowledge and information patterns for a modern solar and bioclimatic architecture ("lessons from the past"). These "patterns" comprise all the phases and aspects of architecture, from the site selection to the detail of an opening or an eaves. The second aspect is that architectural expression should respect the basic elements of local traditional form (regionalism). In hot arid areas the general notation in façade design was to decrease the opening areas and use high thermal mass.

A general distinction between building skins in relation to internal loads (Stein, 1999:192) classifies buildings into '*Internal load dominated*' and '*skin load* *dominated*'. The internal load dominated buildings is generally classified as deep plan buildings that have more space away from the façade affecting zone (and therefore the ambient weather influences), and depending on mechanical and electric systems to sustain human activities. While skin load dominated buildings are identified by their direct contact to the exterior walls and the outside environment, mechanical heating and cooling may be required in these buildings as well due to the direct interaction between occupants and the indoor façade-affecting zone. However this classification has been deducted for moderate climates, in extreme climates such as hot arid regions this classification undermines the role of the façade as a major contributor to building cooling loads. (Burrelsman et al, 1998) In their study of the Arizona Central Library in Phoenix, Arizona USA, concluded that even though internal sources of heat are the primary issues in internal load dominated buildings, envelope design is critical in extreme climates and plays a major part in reducing building energy consumption in cooling load dominated buildings. The role of the façade on increasing cooling loads will be increasing due to the scientific breakthroughs in decreasing the energy consumption of office equipment and lighting.

3.5 Energy Conscious Refurbishment of Buildings

The term refurbishment is described by the concise English dictionary (Pearson, 1999) as a derivative word from 'Furbish' 'as to purify or polish, to rub until bright: to renovate…'. Among professionals and academics, studying the building construction and architecture, other synonyms are used such as ' retrofits' , 'fit-outs', 'reuse', and 'rehabilitation'. Historically, refurbishment of buildings has largely been an accepted procedure especially to building facades in a process well known as *'historical layering'*. This meaning took a different dimension with the massive destruction due to World War II, refurbishment was regarded as a stay of execution pending redevelopment. With increasing economic crises, global consciousness of depleting resources, energy increasing demands, as well as focuses on human consideration in both the built and the built-to-be environments, redevelopment is less favoured to refurbishment. Demolition of existing structures is destruction of an asset and is regarded as an added cost for redevelopment of the site. In this context, office buildings are major economic assets, architectural landmarks in the city fabric, as well as a mirror of architectural trends prevailing in a certain era.

The psychological impact of demolition is best described by (Lynch 1972) describing how people use buildings to define and relate to their urban environment, and warning that removal or displacement of well known buildings can be extremely destabilizing for a community

Although an increasing number of office buildings world wide are being refurbished energy consciousness is still in need of political back up and an increase in professional awareness. (Cook 1997) through a comparative study of 31 refurbished office buildings in Amsterdam, Hamburg, London, New York and Toronto came to the conclusion that energy consciousness in refurbishment was accidental and was not comprehensively or holistically studied within the refurbishment schemes. Focusing on possible enhancements to energy consumption by building refurbishment, took new dimensions by various ramifications to existing building energy codes in the USA, Canada and Europe, but remain to be voluntary adopted. To highlight the need for energy conscious building refurbishment as an economic and environmentally sustainable solution, the Conference of Parties 'COP-5', 1999, recommended that *'in order to meet Kyoto Protocol, (COP-3), advantage should be taken of on going modification and renewal of existing buildings to ensure that investment in improved energy efficiency is made at the same time. Also for new buildings, prompt actions must be taken now to affect building shells that will be around for the next 60-80 years'* (COP 1999). However, the apparent lack of incentive to individuals to adopt energy saving measures is observed in (Burton 2002) who remains sceptical of the ethical commitment of individuals to energy consciousness in refurbishment, arguing that energy consciousness is a long term policy for governments and could only be executed in reality if enforced by thermal codes for buildings.

However in the context of the study as explained in Chapter two, the increasing trend of air-conditioning buildings in Egypt is expected to drive government and building owners and occupants to consider this issue in future refurbishment schemes (Hamza and Elkadi 2000). Therefore, it is important to understand how buildings change, the underlying forces that affect the decision to refurbish, and its limitations, which in turn would affect the thermal improvements measures chosen for the façade.

3.5.1 The need to refurbish:

According to their utilization, buildings and their facades undergo different processes of change. These changes have been categorized into (Brand 1994):

Metamorphic change, as experienced by commercial buildings Continuously changing, as firms adapt quickly, often radically due to intense competitive pressure to perform, to satisfy different and ever changing occupants needs, and to accommodate evolving technologies. Office buildings have a rapidly changing internal dynamics, when failing to deliver services, annual costs of running the building exceeds income.

Steady change, as residential buildings which undergo changes reflecting consciously family ideas, growth and prospects.

Reluctant change, as institutional buildings that are designed to prevent change and to convey timeless reliability of the organizations inside. If forced to change this happens reluctantly and expensively as they are mortified by change. Institutional buildings house bureaucracies, which are not allowed to fail.

Brand's classification highlights various psychological, social and cultural expectations that underpin the changes in buildings that lead to their refurbishment or demolition. However, understanding the change process needs to identify when the decision to refurbish is considered.

(Chandler 1991), identifies the building as in need for refurbishment when it is considered '*obsolete*'. Obsolescence is then sub categorized and defined as:

- '*Physical obsolescence*': the period of time between construction and physical collapse, this type is not suitable for refurbishment.
- '*Economic obsolescence*': the period from construction to the end of occupation, when owners or lessee, cease to gain financial revenue from the building.
- '*Functional obsolescence*': the time for the continuous use of the building for its original function.

- *'Technological obsolescence'*: occurs when services of the building are inferior to present day alternatives.
- *'Social obsolescence'*: when tenants leave the building because it does not satisfy their social status, security, or financial rent capabilities.
- *'Legal obsolescence':* When courts rule against the use of a building due to it's unsuitability for human safety, rights of occupiers to use a certain building.

The benefits of refurbishing the existing stock of office buildings in Cairo are inclusive to all building construction parties;

Developer perspective:

- Prime location in commercial district or residential site;
- Building maybe obtained fairly cheaply;
- Less time spent to achieve planning permissions than for redevelopment and new construction;
- shorter contract duration reducing inflation on building costs;
- Plot ratio maybe more generous in existing buildings;
- Faster available space for occupation and rental;
- Less cost on building than new construction;
- Increasing rental value, or restoring it to its original value.

Government Perspective:

- Less capital investment on urban environment.
- Existing infra structure is still used.
- Reducing CO_2 emissions by decreasing production of building materials
- Reducing CO_2 by improving existing buildings' energy consumption

- Less redundant buildings, thus more safe and controlled urbanism
- Less encroachment on prime agricultural lands on city cordons.

Occupants' perspective:

- Provision of improved accommodation
- New building technology services
- Better indoor air quality

3.5.2 The Scale of Refurbishment:

For traditionally built structures the typical rule of thumb is that they require a medium level refurbishment every 50-60 years and a major refurbishment every 100-120 year. At both break points, a decision has to be made as to whether the building is of sufficient quality to merit refurbishment. For many modern buildings, due to life expectancy of building materials, the time of the first overhaul occurs much sooner than with traditional buildings-after 25-30 years rather than 50-60 years (Cowan 1962-63).

From a structural dimension, (Highfield 2000) identifies six levels of building envelope refurbishment.

1. Retention of the entire existing building structure, together with its internal subdivisions, and upgrading of interior finishes, services and sanitary accommodations. In most low-key rehabilitation schemes, existing stairs would be upgraded in preference of installing lifts, and simple heating and cooling systems would be used, in conjunction with natural ventilation.

2. Retention of the entire existing external envelope, including the roof, and most of the interior, with minor internal structural alterations (inserting elevators shafts, or altering staircases) and upgrading of interior finishes, services and sanitary accommodation.

3. Retention of the entire existing external envelope, including the roof, with major internal structural alterations and upgrading of finishes, services and sanitary

accommodation, but with major interior structural alterations such as insertion of new floors where the original storey height permits.

4. Retention of all the building's envelope walls, and complete demolition of its roof and interior, with the construction of an entirely new building behind the retained façade.

5. Retention of only two or three elevations of the existing building, and complete demolition of the remainder, with the construction of an entirely new building behind the retained façade walls. This

6. Retention of only one elevation, a single façade wall, and complete demolition of the rest.

In the vast majority of building refurbishment schemes, the three first are common, since these are nearly always cost effective. Options 4,5,6, can often cost more than total demolition and new construction, and therefore less economically attractive. 'Façade retention options' are almost exclusively associated with listed buildings, where one or more external elevations must be preserved because of their intrinsic architectural or historic interest.

3.6 The Integrated Energy Conscious Refurbishment Strategy:

(Burton 2002) stated that an energy conscious refurbishment scheme is achievable by integrating architectural strategies and appropriate technologies. A design strategy for energy conscious refurbishment was drawn. Although the author indicated that the main objective of building design is to provide good comfort levels for occupants since this increases satisfaction and productivity, it is not clear in the proposed methodology how this is tested after a technical solution for refurbishment is reached.

The methodology proposed by (Burton 2002), is expanded to include factors that were pertinent to the propositions of this thesis (Figure 2). The original methodology follows a path that only highlights the importance of reducing energy consumption in the building. In this thesis, it is argued that reducing energy consumption targets are not enough to sustain the use of a refurbished building and that any technical solution proposed must be balanced and reassessed with user comfort criteria.

The strategy of attaining an energy conscious refurbishment may be divided into three phases. Phase One, underpins the conceptual framework of this thesis and is discussed in detail in this chapter. Phase Two and Three, underpin the operational framework of the thesis carried out from Chapter Five till Chapter Nine.

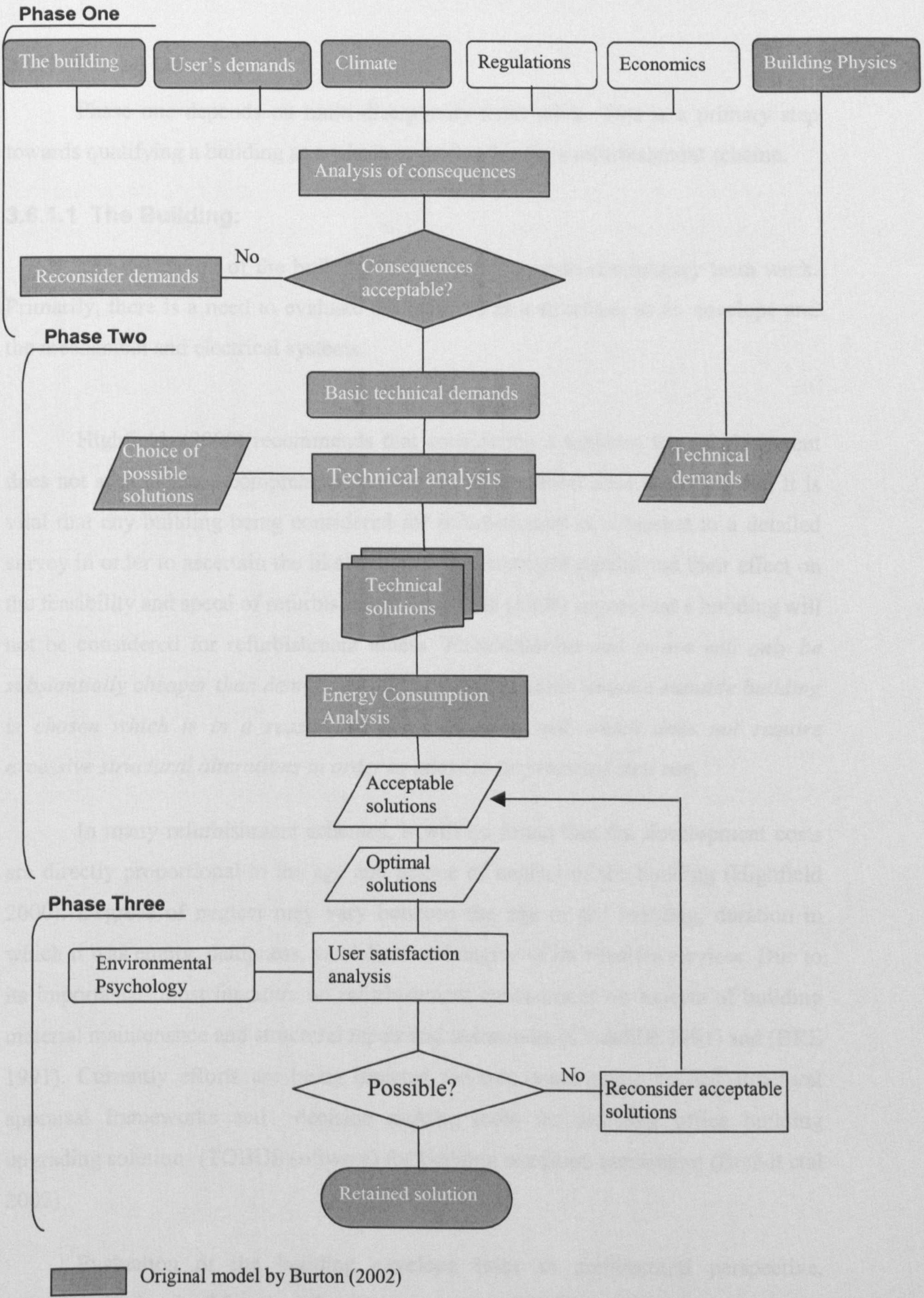


Figure 2: Methodology for an Integrated Energy Conscious Refurbishment Scheme

3.6.1 Phase One:

Phase one depends on multi-disciplinary team work. This is a primary step towards qualifying a building as a whole or its facades for a refurbishment scheme.

3.6.1.1 The Building:

The evaluation of the building is on its own a multi-disciplinary team work. Primarily, there is a need to evaluate the building as a structure, as an envelope and the mechanical and electrical systems.

Highfield, (2000) recommends that considering a building for refurbishment does not start unless a comprehensive audit on its structural state is carried out. It is vital that any building being considered for refurbishment is subjected to a detailed survey in order to ascertain the likely cost of any structural repairs and their effect on the feasibility and speed of refurbishment. Highfield (2000) argues that a building will not be considered for refurbishment unless *'Rehabilitation and re-use will only be substantially cheaper than demolition and new construction where a suitable building is chosen which is in a reasonable physical state, and which does not require excessive structural alterations in order to adapt to its proposed new use.'*

In many refurbishment schemes, it will be found that the development costs are directly proportional to the age and degree of neglect of the building (Highfield 2000). Degrees of neglect may vary between the age of the building, duration in which it was empty, dampness, vandalism and degree of its obsolete services. Due to its importance most literature on refurbishment concentrates on aspects of building material maintenance and structural repair and assessment (Chandller 1991) and (BRE 1991). Currently efforts are being directed towards constructing unified structural appraisal frameworks and decision making tools for selecting office building upgrading solutions (TOBUS software) for building condition assessment (Brandt etal 2002)

Evaluation of the building envelope from an architectural perspective, indicates the level of façade refurbishment needed (3.5.2), the historical value of a façade and aesthetic requirements. The architectural evaluation of the building also includes evaluation of the flexibility of the building for proposed uses.

If the building has installed systems, understanding the properties and age of the system when the fabric is refurbished increases the potential of energy savings. In terms of return, it is better if the fabric and the system are improved together as the potential for energy savings can be realised rapidly than if the fabric was alerted first then the system ten years later.

3.6.1.2 The User's Demands:

Occupants' needs will be discussed in Chapter 4, and in summary include thermal comfort through different seasons, indoor air quality and possibility of natural ventilation, day lighting and electrical lighting levels, and acoustics, protection from fire and burglary as well as providing privacy, environmental control, and flexible indoor layouts. Due to their subjective and qualitative nature, as previously indicated in Chapter Three, occupants' requirements are more difficult to satisfy. Burton (2002) warns that interaction between user demands, climate and the physical state of the building may be complex (such as the interaction with solar protection and daylight, local control and security of the building). Therefore recommends that if the consequences of analysis are incompatible to user demands, then user demands need to be modified to an agreed upon level with the different parties involved in the process and the users (if possible).

3.6.1.3 The climate:

Climate is considered to assess possible building adaptation to its local climatic constraints and opportunities to maximize the use of passive measures to decrease energy consumption while responding to occupants' needs.

Understanding the existing building physics and the prevailing climatic conditions indicates how the building is passively capable of regulating thermal and visual conditions. This understanding allows for a balanced dependence on air conditioning systems whenever free-running conditions would not provide indoor comfort.

3.6.1.4 Compliance with Regulations

Is an inclusive stage combining all previous stages studies then determine alternatives to comply with thermal codes while providing occupants' comfort.

Thermal codes are mechanisms to control the building's skin thermal performance to minimize energy consumption. (Marosszeky 1991), drew light on the constraints on office building refurbishment faced while complying to new building and thermal codes, as a significant economical factor in the overall feasibility studies of office buildings undergoing refurbishment. To determine refurbishment alternatives various calculations methods are used ranging from simple mathematical modelling, building simulation and experimental work on mock ups or part of the building if needed.

Building codes are based on a societal decision that it is important to protect the health and safety of people within the built environment. Building codes and regulations influence every stage of the life-cycle process of a building. Building codes are devised as a regulatory tool to secure the role of the building façade as an environmental moderator in an attempt to reduce reliance on energy consumption in buildings.

Codes regulating energy consumption in buildings have passed through three stages:

The need for energy codes to regulate energy consumption in buildings arose after the first energy crises in 1973. Legislations attempting to enforce the rational use of energy in buildings were issued in oil importing countries and date back to the mid seventies. (USA Japan, Germany, etc)

In the 1980s, trans-boundary problems related to global environmental degradation (acid rain, oil spills), brought new challenges. This strengthened interests in promoting energy efficiency in the building sector in developing and developed countries as a means to reduce the impact of energy production and use, carbon dioxide emissions, ozone depletion and global warming. In the Middle East, Kuwait introduced it's energy conservation regulations in 1983, in Jordan these regulations were introduced in 1985, while in Egypt regulations regarding the thermal performance of buildings were issued in 1998.

Through the 1990s, energy policy priorities shifted, partly due to changing attitudes towards the role of government in energy markets (privatization, etc) and partly in response to climate change concerns. This led to tightening on building energy consumption, and more emphasis on reforming parts of the existing standards to include measures to cover existing buildings' thermal performance.

The Canadian building code (1995) divides regulations of energy consumption in buildings into:

- Prescriptive Envelope regulations
- Trade off Compliance
- Performance based compliance

The prescriptive standards cover the three major components of a non-residential building, the building envelope, the mechanical systems and the lighting systems. In the prescriptive path each component may be shown to comply independently. The prescriptive envelope requirements are determined either by the Envelope Component Approach or the Overall Envelope approach. The prescriptive approach involves standards that specify all of the materials configurations and processes required to achieve a desired regulatory goal.

Performance approaches leave many of these factors open, specifying only the final regulatory goal. Calculations should show that the rate of heat loss through the envelope, and the calculated annual energy use of the proposed building are no greater than the rate of heat loss from a national building of the same size and shape designed to comply with the elemental method (1995).

Performance based regulations offer more opportunities to use innovative, new products and techniques. The design flexibility encourages developers and designers to explore alternative approaches to keep construction costs down while maintaining energy efficiency.

Trade off compliance is a mixture between both methods to reach an approved energy consumption level within the building.

3.6.1.5 Economics

It is commonly understood among professionals and developers that refurbishment to maintain a buildings survival has its limits.

(Pugh, 1991) lists that refurbishment decisions are basically based on its economic return which pays back when:

- It extends significantly the life of a building in the range of 30-50 years
- The difference in rental value between new and refurbished is narrow.
- Redevelopment costs are high

However, decisions of refurbishment solely based on economic values have created many arguments on real value of buildings from a social, cultural and psychological perspective. (Galbraith 1971) puts this discussion into focus by drawing analogies to the construction of Taj Mahl in India '*A modest structure at modest cost would have provided durable and hygienic protection for the mortal remains of Mumtaz Mahl..... It rejoiced the whole world and surely was sound economy. Our test should be similar. The most economical building is the one that promises to give the greatest total pleasure for the price*'

As refurbishment of building facades also involves the urban context, façade refurbishment came under scrutiny and a wide theoretical debate about the meaning of the built heritage for the society, the choices about what is to be conserved, the interpretation of the past and the effect of conservation on creativity. It is a subject of increasing relevance at a time where rapid changes in society and pressures for development affect the way that people think about their environment. The use of new materials and technologies for façade refurbishment is then argued to give the historic areas an appearance of continuing evolution (Loew 1998). Lynch calls the process 'layering' where the visible accumulation of overlapping traces from successive periods, each trace modifying and being modified by the new additions, to produce something like a collage of time (Lynch 1972).

Within the context of Cairo, the long tradition of judging building alternatives on solely economic basis may not provide proper alternatives for building refurbishment. Office façade refurbishment must not be looked upon as an economic assemblage of component technologies, but as an integrated technique to achieve the three pillars of architecture (Commodity, firmness and delight) integrated with environmental consciousness and energy efficiency throughout the façade life cycle. In this case, balancing economics of refurbishment solutions with effective commercially, socially and environmentally measurable benefits with offer the chance to utilize new technologies to attain users' comfort while reviving and fine tuning bioclimatic and sustainable design approaches that were ignored due to reliance on mechanical environmental control systems.

3.6.1.6 Building Physics:

Examining the existing building physics reveals opportunities to adapt the building to its local climate to provide users' comfort with least dependence on mechanical systems. This aspect is more related to Phase two as finding the appropriate energy conscious refurbishment options depends on technical solutions provided to integrate the building and its systems to reduce energy consumed to provide comfort to occupants.

3.6.1.7 Analysis of Consequences:

The interaction between the building, the climate and user demands is complex. Fine tuning these demands to comply with codes and economics is a further challenge for the design teams. If the consequences are incompatible or unacceptable conditions are predicted then an iteration process starts by re-evaluating the demands. If consequences are acceptable and agreed upon within the design teams then the scheme is moved to Phase Two where basic technical demands may be considered.

3.6.2 Phase Two:

At this stage basic technical requirements are studied. These technical requirements are examined seeking options that may integrate passively to building and its systems to enhance their performance in providing user comfort.

These technical options are then analyzed using quantified variables deducted from phase one and tested by various methods such as simulations, experimentation and mathematical modelling. This chapter reviews the basic technical requirements stage. The rest of the steps illustrated in Figure 2, are discussed in detail in the operational framework in Chapter Five.

3.6.2.1 Basic Technical Demands

(Kendrick et al. 1998) developed office building refurbishment criteria based on office energy consumption levels (Table 1).

Table 1: Refurbishment levels according to building loads based on (Kendrick et al. 1998).

Heat Gains W/m^2	Level of Refurbishment
15-20	**Level 1: Minor Refurbishment:** Opening windows, install modern blinds, repaint interior, redesign interior layout
20-25	**Level 2: Intermediate Refurbishment** Opening windows, install modern blinds, renew lighting, repaint interior, remove false ceiling to expose thermal capacity and raise ceiling height
25-35	**Level 3: Major Refurbishment** Opening windows, install modern blinds, renew lighting, repaint interior, remove false ceiling to expose thermal capacity and raise ceiling, possibility of using stair cores as stacks, Building Management System to control night cooling with motorized window/vent opening
35-45	**Level 4: Complete Refurbishment** Opening windows, install modern blinds, renew lighting system, repaint interior, remove false ceiling, use stairs as stack, BMS controlled night cooling. Radical changes to air flow path by addition of atriums, use of double facades to drive stack ventilation.

The level of refurbishment chosen will depend on a variety of economic, structural and legislative constraints. The first level is often the most desirable because it is significantly cheaper, and produces faster accommodation than the other three levels. However according to the classification it is more appropriate to conserving energy in buildings that originally less levels of energy consumption. Following this classification, and in light of understanding of the office building energy consumption in Cairo, this thesis aims to look at possible refurbishment options on level four as they are suitable for the higher energy consuming office buildings. As the thesis looks into façade refurbishment, the scale of refurbishment (3.5.2) assumes a level 2 according to Highfield's classification, where the entire building and its envelope are retained as an architectural configuration, with possible changes to building façade materials by addition or substitution to enhance the façade thermal performance to decrease cooling loads on the mechanical systems.

The basic technical solutions recommended by (Kendrick et al. 1998) in (Table 1), recommends opening windows for natural ventilation to reduce energy consumption in moderate climates. The difficulty of providing natural ventilation during working hours in Cairo has been previously discussed and therefore all strategies to improve natural ventilation were excluded from the analysis. Renewing lighting systems is assumed as an energy conscious measure. However, the double skin façade as an option for energy conscious refurbishment was considered in detail as a solar radiation shield to the building rather than an opportunity to use natural ventilation.

3.6.3 Phase Three:

Phase Three considers reaching a balanced decision on refurbishment options balanced by user satisfaction analysis. User satisfaction and environmental psychology aspects underpinning the relationship between occupants and facades are discussed in detail in Chapter four in this thesis.

3.7 Double Skin Façades as a Façade Refurbishment Option:

Using double skin façades as a refurbishment option requires understanding of its origins, its inherent properties and examining precedents of its use as an option for energy conscious façade refurbishment.

3.7.1 Definition:

Wigginton and Harris (2002:41) define double skin as a system, involving an added layer of glazing to the façade for maximizing daylight and improving energy performance.

Double skin facades have been defined as: a ventilated façade acting as a multifunctional thermodynamic system used to combine both outdoor ambient aspects and building passive behaviour. For exhausting the warm rising air, the air channel can stand-alone or integrate with heating, ventilation and air-conditioning systems (HVAC) (Balocco 2002). Between the outer and inner layer of a double configuration, a buffer zone is created, shielding the inner single façade from direct environmental factors, and allowing for the safe installation and maintenance of shading systems (Oesterle et al 2001).

3.7.2 The Evolution of Double Skin Façades' as a Façade Technology:

The roots of Double skin facades are linked to the European green houses and the French 'orangerie', established in the early nineteenth century, then developed into massive horticultural conservatories in England. Horticulturalist in Europe and the States promoted the idea of a sun spaces as a possibility of circulating warm air into the adjoining rooms, encouraged by the construction of the Crystal palace in 1851 by Paxton and the possibility of constructing large scale structures of glass,. In 1860 in The Gardeners Chronicle in the UK, Jacob Forst suggested that south facing glass walls creating sunspaces could be used to grow fruit, and would provide "*an admirable arrangement for house ventilation*" (Wigginton 1996).

The first idea to use double skin facades as a climate moderator controlled actively by mechanical systems is linked to Le Corbusier and his idea of the "murs neutralisants". In his project for the Cite de Refuge, the Salvation Army Hostel in Paris, Le Corbusier's envisaged "*our invention, to stop the air at 18?'. These walls are envisaged in glass, stone, or mixed forms, consisting of a double membrane with a space of a few centimetres between them ... a space that surrounds the building underneath, up the walls, over the roof terrace. Another thermal plant is installed for heating and cooling, two fans, one blowing one sucking; another closed circuit. In the* *narrow space between the membranes is blown scorching hot air, if in Moscow, iced air if in Dakar. Result, we control things so that the surface of the interior membrane holds 18.'* Although the propositions were examined by the French glass manufacturer, St Gobain, in 1931, the proposition was never carried out. The St Gobain report would have read "To place heating and incandescent elements between the walls is in most cases not to be recommended, since by this means too much warmth or cold is lost to the atmosphere"(Wigginton and McCarthy 2000).

In 1935, the development in glazing manufacturing brought to the markets of "Thermopane', a double glazing unit manufactured by Libbey Owens Ford (LOF) comprising two sheets of glass hermetically sealed, with a 12mm air gap. The Concept had its roots in windows constructed in European cottages in cold climates where double panes of glass were operable either to trap heat in-between panes in winter, or open the two panes completely for natural ventilation in summer. In Europe the Steiff Factory is an early example of using double panes windows in a non-residential building. The air in the gap was then integrated to the building air-conditioning systems. The air gap then is transformed into a mechanically ventilated cavity in which air is circulated by either mechanical systems or by differences in pressure between room and cavity. In Both cases, the room air exhaust is drawn by mechanical equipment for circulation in air conditioning systems or to the outside environment. The inner glass pane maybe opened for cleaning. The earliest examples of this model are, the museum of arts and crafts in Frankfurt am Main by Richard Meier, built between 1979-1984 and the Lloyds Insurance Company in London by Richard Rogers1978-1986. Where warm room air is extracted above lighting units to the window cavity where it is further heated by heat from direct sun radiation then drawn to the air conditioning system. It is claimed by the architects that the system improves thermal comfort beside the window areas and reduces costs for heating and cooling.

On another front, the early twentieth century saw significant efforts to utilize solar energy in architecture. In 1931 Martin Wagner in Germany was able to produce his competition 'the growing house' in which a glass skin protected the outer walls of a building. The idea of controlling solar energy by means of combinations of mass and glass took root. The Peabody house, in Dover Massachusetts is considered a pioneer in incorporating the essential features of passive solar energy. In 1961, A E Morgan built St. George school in Wallasey (currently used as council offices) what maybe considered the first solar double glazed façade in England. In which an inner translucent and clear glass layer was separated by 60cm to an exterior layer of clear glazing, heated air is driven through a massive roof and floor to heat up the building. Some of the inner panes are reversible panels blackened from one side to absorb heat and polished aluminium on the other side to reflect sunlight. (Wigginton, 1996:97). During the 1960, two streams of architectural facades, the curtain wall and the solar wall, drifted in progress. Only to return to perform together in a powerful unity by early 1980's as a transparent double skin façade. This advancement can be attributed to both advances in manufacturing of glazing process and additives that complemented the glass thermal and visual performance and the second is the advancements in glazing fixations and seals. The evolution was used by architects in Europe to utilize all physical and structural capabilities of the two systems combined to produce a climatically interactive multi layered façade. The double skin façade is also referred to as a passive climate façade in literature.

The double skin façade configuration has been realized in many projects that reached fame world wide. Examples of these buildings are well illustrated in many separate architectural publications, but a detailed account may be found in (Compagno 1999; Wigginton and Harris 2002). Examples include the Willis, Faber and Dumas building by Foster associates in Ipswich (constructed 1975), Occidental chemical centre in New York, USA by Canon design (1980), 'Headquarters of the Swiss Insurance Company' (1991-1993) in Basle by architects Herzog and Meuron, 'Galleries Lafayette' in Berlin (1991-1995) by Architect Jean Nouvel, 'Commerzbank Headquarters' (1991-1997) by Sir Norman Foster and Partners, 'Stradtor' (1991-1997) in Dusseldorfer by Petzinka, Pink and Partners and Super Energy Conservation Building in Tokyo by Ohbayashi-Gumi. However, these buildings are predominantly constructed in moderate climates. Double skin façade are still under scientific scrutiny and optimization of its design and components is still not understood. While the façade technology is claimed to moderate climates of Europe indoors, its function as a climate moderator in hot arid areas is scarce. Therefore, this study aims at studying the potential of these multi layered systems in hot arid climates.

3.7.3 Double Skin Façade Types:

Characteristic to the double skin façade configuration is the air cavity, which is created by adding a single sheet of (mostly toughened) glass to the original facade. A solar control device (mainly louvers blinds, but other systems are possible) is added inside the cavity directly behind the outer sheet of glazing. The air cavity is ventilated mechanically or by buoyancy. Although it is possible in principle to choose the direction of the air-flow either up or downwards, it is better and more 'natural' to create an upwards flow.

The advancements in glazing manufacturing in terms of its physical ability to control heat loss or gain and the possibility of using it as structural walls, created the possibility of using double skin façade configurations with different internal partitioning. The expression is now used to describe a façade constructed with a variety of sophisticated enclosures that can flexibly adapt to environmental conditions. The façade technology allows for a flexible regulation of heat, cold, light, wind and noise. Double skin facades are constructed with various internal configurations that vary between boxed windows, corridor facades, or vertical shafts.

(Oesterle et al, 2001) divided into four different principles (Figure 3):

1. Boxed window types-separate systems for each story. Boxed windows are constructed with a horizontal and vertical separation between the different stories of the facade. Each box window element requires its own intake and extract opening.
2. Shaft-Box facades: these extend horizontally over a number of building stories and have vertical separators. To utilize and exploit the thermal uplift of the inner air fewer openings are required for the outside skin.
3. Corridor Facades: where the second skin extends horizontally to separate between building floors. Openings for air intake and extract are usually situated on the lower and upper sections of the outer skin.
4. Multi-storey facades: where a glazed curtain wall systems is positioned in front of the inner facade without any horizontal or vertical separation. Between these two layers, the air can circulate freely. It is most suitable when sound reduction is

required, as the large openings for intake and extract are only situated on ground and roof level.

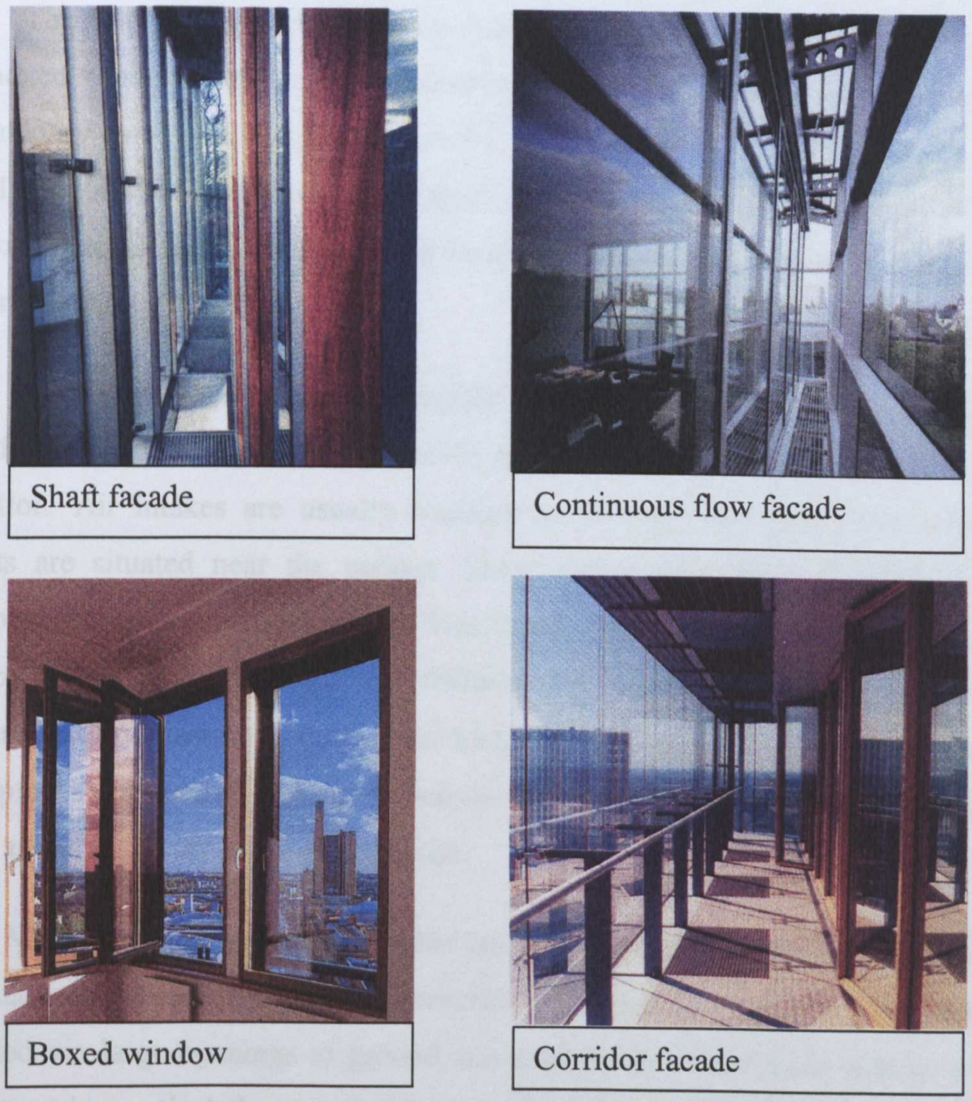


Figure 3: Types of double skin facades (Photographs Courtesy (Oesterle et al. 2001))

The earlier versions of double skin facades are boxed windows. The boxed window is a classical example of a multi layer environmental protection for a window. However, the modern adaptation for the concept is seen in the Postdamer Platz block no.1 (completed 2000) in Berlin by architect Hans Kollhoff. The air in between the pane passively controls heat transfer to the outer atmosphere. It constitutes of an outer clear pane and an internal low emissivity glazing pane. Its combination of a classical configuration of a low-e window but with an interactive air gap that may be opened in summer to exhaust unwanted hot air or may be closed in winter to trap the hot air and act as an added insulation for the glazing configuration thus reducing thermal asymmetry and building heat loss.

The Shaft boxed Facades thermo-physical properties depend on a combination of a boxed window system and a solar chimney. It consists of two layers of glazing separated by an air gap that extends over a number of floors to create a stack effect. Boxed windows are connected to this shaft so that the stack effect draws the air from the box windows into the shaft and this air is exhausted by the vertical hot air rising in the vertical shaft.

In corridor facades, the intermediate space between two skins is closed at every floor level. Vertical divisions maybe applied in cases where for acoustic or fire protection. Air intakes are usually situated on the near the floor level while air extracts are situated near the ceiling. These continuous spaces may function as corridors for movement or balconies. This system has been used in Dusseldorf City Gate by Petzinka and Partners in 1998with the outer façade being of a 12mm toughened safety glass, and low-e glass for the inner façade. Direct solar radiation is intercepted by reflective aluminium louver blinds in the intermediate space of the façade and is set closer to the outer façade.

Multi-storey facades, are constructed so the intermediate space between the inner and outer facades is left unobstructed for continuous air flow. The space is ventilated via large openings at ground and roof levels. The façade acts as a solar chimney and a vertical thermal flue by buoyancy of hot air rising upwards. Multi-storey facades are particularly suitable where external noise levels are high, since this type of construction does not require air intakes or exhaust distributed over its height.

In summer, to keep cavity temperatures down ventilated air is drawn through the bottom of the façade and out at the top through motorized dampers. The summertime performance creates a cavity that intercepts solar gain and protects offices from direct solar radiation. It encloses and protects additional shading devices, louvers and walkways. Fixed and moveable shading systems absorb heat from solar gain, creating air currents which draw in cool air from the low level openings to the cavity.

In some cases, more than one type of double skin facade may be incorporated in the same façade. (Tenhunen et al. 2000) draw attention on the possibility of extending the use of the double skin façade configuration from a protector against the adverse climatic and environmental condition, to become a 'green circle' where the façade creates its own micro-climate by enclosing large indoor gardens such as atriums. The double skin façade may also be configured as an 'energizer' where PV cells are integrated to create an environmentally conscious façade.

Following the technological advancements in mechanically controlling the air gap in the double glazing windows, the concept of using mechanically ventilated cavities was recently applied to double skin facades such as the Union Chimique Belge (UCB) (Kragh 2001). The mechanical integration between the building systems and the air cavity is claimed to reduce accumulation of heat build up in the cavity while the heated air is used in the air-conditioning system. However, the energy savings from using the double skin facades maybe outweighed by the utilization of fans for circulating air in the cavity and still needs justification.

3.7.4 Advantages and Disadvantages of Double Skin Facades

Since the increase in the use of double skin facades after the 1980's, the façade technology has been under continuous scientific scrutiny. However, like any facade technology, double skin facades have advantages and disadvantages that have to be weighed and studied carefully, before they are used in refurbishment or new built facades.

The advantages of Double skin Facades are multiple:

- Controlled transmission of solar radiation into interior spaces;
- Due to its transparent configuration, no reduction of the view area available from the original skin (inner skin) configurations occurs;
- Reduced noise pollution indoors, especially in heavy traffic urban areas.
- Minimizing the temperature differences between the air in the room and the surface of the glass wall. This improves the thermal comfort conditions in the office space nearer to the wall and thus reduces energy costs for heating in winter

and cooling in summer. Improving comfort conditions near wall areas improves the efficiency of floor use;

- Unlike single façade construction due to the addition of the external façade layer in a double façade construction and air intakes and exhausts are well secured with fins, no rain ingress problems, security risk, dust or insects in conjunction with night-time ventilation are expected

- The external façade protects the internal façade from destructive environmental forces, thus decreasing investment in up keeping the building, especially in listed buildings.

- In case of shaft or continuous double skin facades, due to the buoyancy effect, the upper floors experience higher cavity temperatures than lower floors. In this case small power fans maybe used to extract the excessive heat. However, the fan's electricity consumption need not outweigh the benefit of double skin facades. The excessive heat may also be used with a heat recovery system to feed into air-conditioning systems.

- Daylight enhancing systems such as prismatic glazing, reflective blinds, automated sun shading systems are expensive technologies that are best protected from the ambient environment when used in the enclosure of double skin facades;

- The exterior protective layer of glass facilitates operating shading and daylight enhancing devices year round and in any weather. This protection offers easier maintenance and replacement whenever needed;

- In architectural terms, the ventilated cavity wall is one of the few feasible possibilities of using a fully glazed wall

But there are also some disadvantages:

- Because of the airflow, the inner sheet and the blinds pollute quickly. In order to clean the inside of the cavity, the inner single sheet must be made to open. This can be done by sliding or hinging.

- The system works best when the outer sheet is closed. Nevertheless in many cases the facades are equipped with windows that open up onto the outside, thus disturbing the airflow greatly.

- The heat insulation properties are much better than that of a normal, double glazing facade, because of the extra insulating properties of the ventilated cavity which is an advantage in moderate climates, but maybe considered a disadvantage in a hot arid context.

- Noise propagation within the space need to be controlled. This is currently achieved in moderate climates by separating the gap by horizontal services corridors on each floor level (these maybe perforated to influence cavity air flow to a minimum). However, the effect of separating the gap into corridor double skin facades needs to be studied in hot arid climates.

- The risk of fire propagation in the cavity is considered higher in continuous cavity double skin facades. The problem in office buildings is not in saving people as normally two fire escape routes would be found in buildings. However, the risk is associated with the spread of fire and its control in the building. The glazing layer on the outer surface is normally designed to allow for expansion and unscrewing from the outside which in the case of fire maybe used to dismantle certain panes to control the fire. However, additional forms of fire protection maybe used in the cavity such as automatic early fire warning signals, additional measures to ventilate the intermediate space, and sprinklers systems.

Double skin facades although based on vernacular concepts of architecture in combining the façade with the building services remain till now a relatively unrealised building concept in the real built environment. This is attributed to little experience with the behaviour of multi layered facades in operation, whether from a physical, psychological or economical dimensions (Oesterle *et al*, 2001).

3.8 Case studies of Double Skin in Facade Refurbishment:

This section aims to explore examples of the use of double skin facades as an integral part of a refurbishment scheme. Contrary to new constructed buildings with double skin facades, scarce information was found on refurbished with double skin façade buildings, and their effect on the original building's energy consumption.

3.8.1 Case (1) BCT Telus Communication headquarters

The building is an eight-storey high-rise situated in downtown Vancouver, Canada. The 1940s section of the Telus William Farrell Building (Figure 4) commonly known as BCT Telus Communication headquarters along Robson Street, is a refurbished building where the original wall system was transferred into a multi layered façade (CCE 2001). In rehabilitating the building, the designers added a second skin of glass outside the original walls to create a buffer layer. The inner skin uses operable windows to let the occupants enjoy fresh air whenever the cavity air temperatures are favourable.

The building's new exterior glass skin is suspended one metre away from the existing building face. Motorized dampers and photovoltaic powered fans assist in moving the air up and out of the plenum when necessary and work in tandem with the operable windows. The exterior glazing is a combination of fritted glass panels to reduce solar gain, combined with clear glass that allows the occupants to see outside. Light shelves are also installed above the existing windows to help daylight penetrate inside the building. After running simulations, a double glazed exterior skin was constructed in order to avoid condensation.

There was no information found to compare the previous and existing levels of energy consumption of the building, but it is claimed that the use of double skin façade is projected to reduce energy consumption in the building to 65% of the consumption levels set by the Vancouver Energy by-law.

Figure 4: BCT Building, Vancouver, Canada, (Source CCE).

3.8.2 Case (2) Glasbacher Bank:

Gladbacher bank is situated in Monchengladbach in Germany. The building is five storeys high refurbished in 1995 (Figure 5). The South facing façade was inadequately insulated. As the building was on a busy traffic junction, indoor noise levels were unacceptable. Architects Schrammen und Partner decided to use a double skin façade as part of building the refurbishment scheme to improve the façade's thermal and acoustic properties. The façade works as a shaft double skin façade with natural buoyancy. To improve the performance of the façade as a climate moderator, and as it faces the Southerly high levels of direct solar radiation in winter, the exterior glazing is of reflective nature. Natural ventilation is predominantly possible, due to double skin façade configuration while reducing the noise levels indoors despite the heavy traffic noises. Whenever the temperatures in the cavity are suitable, natural ventilation or night time ventilation are possible (Oesterle et al. 2001).

Figure 5: Gladbacher Bank before (left) and After (right) refurbishment with a double skin façade, courtesy (Oesterle et al. 2001)

3.8.3 Case (3) BML Headquarter

The BML headquarters in Bonn, Germany is used by the Federal German Office for Building and Regional Planning. The architects Ingehnhoven Overdiek und Partner with their façade consultants DS Plan decided to refurbish the existing facade by adding an exterior skin to improve its poor thermal performance. The poor thermal performance was attributed to windows constructed in clear glazing and poorly insulated wooden casements (Oesterle et al. 2001). The original Vertical sun louvers separating the windows were used to mount upon the exterior layer of the double skin façade (Figure 6). The double skin facade used is a boxed window type with the possibility of opening inwards the exterior glazing (fixed by pivots) on the outer façade in front of the windows whenever natural ventilation is required. However, no information was found on the improvements to the building's energy consumption levels after refurbishment.

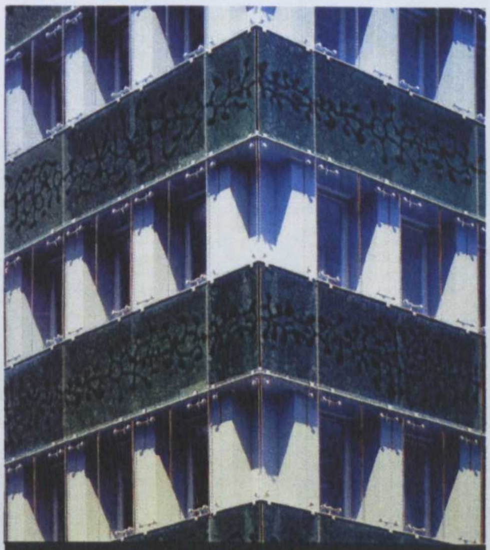


Figure 6: BML Headquarters, courtesy (Oesterle et al. 2001)

3.8.4 Case (4) Swiss Insurance Company SUVA Headquarters:

The SUVA Building is situated in Basle, Switzerland. To unify the architectural façade expression of the old building with its new extension, architects Herzog & de Meuron refurbished the old building facades with a double skin (Figure 7). The original building was constructed in the 1950s and with a façade typical regular arrangement of hole-in -the-wall windows. The new double skin façade is placed one meter away from the original façade. The exterior layer is a complex system. This type of a façade is separated at each floor, which is considered a corridor façade. At each level the double skin façade exterior glazing has triple horizontal banding with top hung windows. The upper and lower bands are of insulating panel with integrated prismatic panels claimed to increase penetration of day lighting indoors while acting as a solar shading device(Wigginton and Harris 2002). The middle band at window level is of transparent insulating glazing. The upper and lower glazing bands are automatically controlled to open in summer to exhaust air in the cavity and prevent it from over heating the interior stone façade. In winter, all the façade is closed to trap heat in the cavity thus creating a heated buffer zone around the building decreasing its U-Value from 3 W/m^2K to 1.2 W/m^2K. The façade allows for manual override of the system if occupants perceive the need to open the exterior glazing panels. The possibility of adjusting the glass panels allows the façade to react in response to the varied climatic conditions.

Figure 7: SUVA Building before (left) and after (left) refurbishment with a double skin façade Courtesy (Wigginton and Harris 2002).

3.8.5 Case 5: Umbau Deutshe Bank

Double skin took another dimension in historical building conservation in façade alterations to the Umbau Deutshe Bank in Berlin (Figure 8). The original concept of the building's refurbishment depended on extending the building by two storeys, cover the atrium by glazing but otherwise restore the original building façade. The result was a historic building dressed in a glass cloak. A highly transparent second skin was chosen to unify the façade of the existing building and its extension. The façade is naturally ventilated by a multi-storey second skin system of construction. To improve the thermal performance of the existing façade double panes (with a U-value of 1.6 W/m^2K) were used.

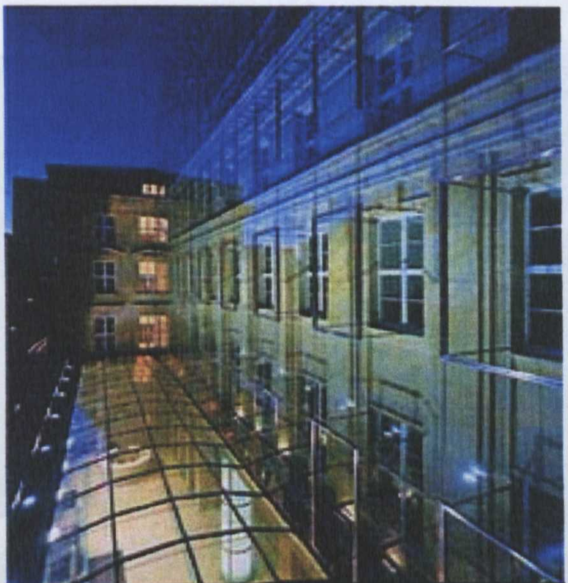


Figure 8: Deutche BankPhoto: by Juergen Schmidt in Space moderator (2000)

3.8.6 Case 6: BP Amoco Building.

In order to perform as an environmental moderator and an energy provider BP Amoco building built on the campus of the Norwegian University of science and Technology in Trondheim combines two façade strategies (Figure 9). A double skin façade integrating Photovoltaic has been constructed as a second glazed envelope on the existing office building. The solar skin is a continuous cavity with air intakes situated on top and ground levels of the façade. The solar skin is composed of clear glazing in front of existing windows and photovoltaics in front of the existing opaque areas. Airflow through the cavity between the solar skin and the building wall is via automatic openings at the base and top of the wall. The openings are controlled by climatic conditions. In addition to appearing with a new attractive facade, the building now generates environmentally friendly electricity and at the same time the building's heating requirements are reduced (BPSolar, 2003).

Figure 9: BP Amoco Building

After a year of monitoring researchers concluded that (BPSolar 2003):

- Daylight reduction is quite large, but light levels inside are still well within the building code requirements.

- Heating demand for the building behind the new facade was reduced 7 to 8%.. Overheating was experienced in the upper floor in summer, so the automatic cavity exhaust system needs reconsideration.

3.9 Summary

This chapter reviewed the various roles expected from a façade, with emphasis on its role as a climate and environment modifier and its effect on the building energy consumption. Following an international agenda to preserve the built environment refurbishment of building is seen as a viable option against demolition. The scale of refurbishment and its limitations are reviewed with an understanding that not all buildings can be refurbished. However, refurbishment of buildings offers to preserve the historical and cultural aspects of an urban fabric, to prevent further unsustainable extraction and utilization of building materials, to preserve diminishing fossil energy reserves used in the processes of construction and material extraction, to prevent creation of Brownfield's and to minimize urban encroachments on economically valuable lands.

- Increasing competition for tenants will force owners of older buildings to renovate to compete with newer buildings. The lack of prime new urban sites, and the general interest in preserving architectural landmarks will lead to favouring refurbishment and will contribute to a shift from the Era of building to the Era of Re-building.

- The chapter proposes an integrated energy conscious strategy that underpins this thesis methodology, highlighting the relation between refurbishment options to conserve energy balanced by occupants comfort in the work place.

- Although refurbishment is commonly assessed on stringent economic bases, the delight, attractiveness, and pleasure that a building may offer must also be a major factor to be considered in the judgment of a proposal.

- Double skin facades have been identified as a possible technical façade refurbishment solution. Its performance as a climate moderator is built upon knowledge of the performance of solar chimneys, advancements in glazing options and curtain walls construction.

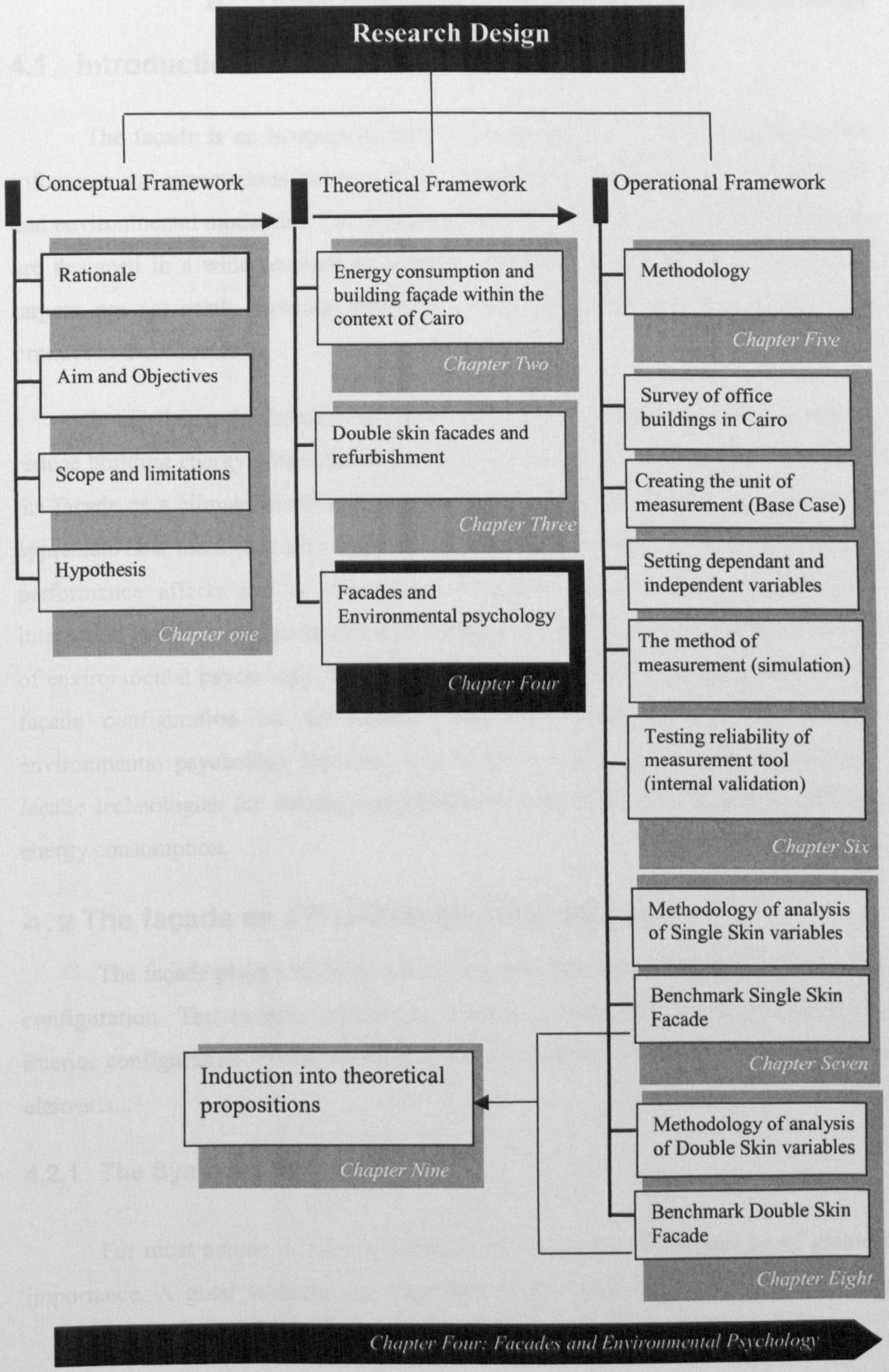
- Finally six case studies illustrate how double skin facades have been used with different configurations and portioning of the air gap in refurbished projects in Europe and Northern America. However, the façade technology is still in its infancy and requires more monitoring studies to truly quantify its advantages and disadvantages.

- Double Skin Facades as a form of a transparent façade technology has not been used in hot arid climates, and therefore it needs several studies to understand its potential especially as a façade refurbishment option

Chapter Four: The façade and environmental psychology

Key Concepts

4.1 Introduction
4.2 The Façade as a psychological manipulator
4.3 facades and occupiers' comfort and control


Research Design
Conceptual Framework
Theoretical Framework
Operational Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
The method of measurement (simulation)
Testing reliability of measurement tool (internal validation)
Chapter Six
Methodology of analysis of Single Skin variables
Benchmark Single Skin Facade
Chapter Seven
Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
Induction into theoretical propositions
Chapter Nine
Chapter Four: Facades and Environmental Psychology

4 The Façade and Work Place Interaction

4.1 Introduction:

The façade is an inseparable part of a building; its role responds to various influences and expectations that may either strengthen or weaken its role as a climatic and environmental moderator. This chapter attempts to give an insight on how facades are designed in a wider context to respond to several design targets. These design targets, are not easily separated but tend to fuse to produce the final façade as a product to these forces.

In this thesis, the façade is recognized an integral element in building design to reduce building energy consumption and increase occupants' satisfaction. The role of the façade as a climate, environmental, and psychological moderator is discussed to appreciate how the façade affects the enclosed indoor conditions, and how in turn, its performance affects and is affected by occupants' psychological demands. The interaction between occupants and their working environment are founded in theories of environmental psychology. It is the aim of this chapter to discuss the effect of the façade configuration on the interior environment and relate it to pertinent environmental psychology theories. This relation is used to balance the proposed façade technologies for building refurbishment with needs for decreasing building energy consumption.

4.2 The façade as a Psychological Manipulator:

The façade plays a multiple role in manipulating psychological reactions to its configuration. The exterior appearance reflects the symbolic messages, while its interior configuration affects the behavioural interaction of building occupants to its elements..

4.2.1 The Symbolic Message:

For most people it is the appearance of a building, which will be of greatest importance. A good building can contribute to the sense of pride and place (This common inheritance, 1990). The façade configuration sends symbolic signals[1] to passers-by while influencing the occupier's perception of the indoor space and the individual's control on the indoor environment. However from a thermal performance point of view it has been argued that historical buildings whether public or domestic had an improved thermal performance than modern buildings due to the availability of heavy thermal mass utilized in facades (for structural reasons) as opposed to the increased glazed areas in modern building facades. An argument that fails to consider that historically the facades of buildings were responding to a cultural agenda that has changed and was represented in changing the facades physical properties.

Human requirements and perception of the façade is imbedded in the subconscious, it is a built up of experiences that date back to the oldest buildings in human history. In Ancient Egypt the temple were classified as cult and mortuary temples. The Cult temple of which the temple of Khons :Karnak stands as an example, takes its role as an economic, educational as well as a religious institution. The façade of temples were used for pictorial representations of the might and power of the ruling Pharaoh. The high symbolism of diminishing the human scale in the hands of the Gods, and the immortality of ruler and his political powers was not only reflected by the magnified scale statues or depicts of Pharaohs but the building material used. Its exterior walls built out of cut stone reserved only as a building material for the finest buildings of religious character (mud and clay bricks were used for all other forms of buildings). However these facades performed a linguistic and literate text. (Quincy 1803) observing the Ancient Egyptian Monuments , of which façade depicts play a substantial part, were public libraries, as the purpose of their massive solidity and smooth surfaces was not an aesthetic effect but to carry inscriptions.: '*In the most literal sense, the public records of the people, which religion and government imposed upon them, this educational faculty, without doubt made it a sacred obligation to render eternal these monuments, which were not in a metaphorical sense, the depositories of customs, beliefs, exploits, glory and ultimately of the philosophical and political history of the nation*'

[1] The symbolic signals are defined as :'a kind of shorthand reducing the complexities of life to manageable proportion, it is used tactically as a method of ordering and disciplining emotional experience, it gives additional meaning to that which is communicated by its superficial configuration or profile.' Smith, P. (1979) *Architecture and the Human Dimension*, G.Godwin.

In Hellenic times the civic life was separated from the religious life, the evolving Agora was surrounded by strictly ordered colonnades that sometimes had rooms behind them where official, judicial, and civic life took place. Again the cultural influence is evident, reflecting wisdom (the ionic order), equality (in its repetition), and an opened and democratic façade in the colonnade that faces the Agora.

Gothic architecture appeared with its remarkable breaking away from the architectural inheritance of Greece and Rome. Facades emphasized the change of the society's religious believes into Christianity. The evolution of the style itself is attributed to intense and incessant brooding on the theme of the great church and the right form to built it. The techniques and skills behind the construction that evolved without interruption for a period over 400 years. Gothic Cathedrals apart from being used as halls for prayer were used as community centres, courts of law, theatrical and musical presentations(Fletcer, 1996). The succession of novel forms of construction and decoration and carvings on the façade with their general disposition of figures and narrative of cathedrals to impress and educate the illiterate Christians (bible of stone). Victor Hugo asserts in his book *Notre Dame of Paris*, that until displaced by the printed book, in the middle ages even dissident ideas were articulated through architecture, for thought was free in this mode, and so it was written out in full only in books known as architecture. Hugo proceeds to explain that '*Gothic architecture had been the most complete and permanent record of human thought and history*' (in Forty, 2000). Gothic facades symbolize the power of the Christian religion as well as the achievements in structural systems. It is in Gothic facades the flying buttresses and thin articulated columns and vaults served the structural function of carrying the roofs liberating the walls from their load bearing role for that first extravagant use of coloured glazing depicting the social and religious believes of the time thus introducing the first dramatically day lit spaces, which was used to enhance the religious beliefs of the spirituality of the religion, by the passing rays of light through the story telling stained glass on the facades.

Victor Hugo explains why this role of architecture as a written book of history would change; '*as human ideas changed form they would change their mode of* *expression, so that the book of stone so solid and durable, would give way to books of paper'* (Quincy, 1803).

The façade took a role of an embellished frontier to a building reflecting ornaments and political power and wealth well into the architecture of renaissance. Façade design had imposed the formal discipline of repetition to screen individual variations. The emergence of Renaissance gave the façade an added role of an urban space controller and modifier. King Henry IV (the Place des Vosage now) has invited citizens to build houses around the square of Place Royale but had to erect a pre-designed façade forming an arcade around the square (Ballon, (1992) and Habraken, (1998), (Figure 1).

Figure 1: Building the façade before the building. Source: (Habraken, 1998)

In 1686 Louis XIV took this notion of a façade as an urban modifier to another extreme, commissioning Jules Hardouin Mansart to construct an urban façade to the enclosed orthogonal urban space of the Place Vendome. A uniform freestanding façade was erected and individual owners would then build their own buildings behind it.

This trend of a façade acting as part of the urban infra structure is also demonstrated in Georgian facades of circles and squares of Bath and London, there the design of the façade remained unchanged despite adaptations to the plans and partitions behind them. In Amsterdam the block long urban facades dating back to the 1920-1930's were built by developers, who by law had to commission architects (from a special list provided by the authorities) for façade development. Architect's stating that ' a bad plan with a bad façade was worse than a bad plan with a good façade' as a result uniform repetitious plans of no distinction were screened with exuberantly detailed and sculpted façade (Dennis, 1986)

The emergence of Renaissance and then Neoclassic architecture could be characterized as the international architecture of its time, its elements and orders were soon transferred to all major capitals of Europe in the eighteenth century (Allsopp, 1974) reflecting another divergence in the symbolic message transferred to the society through facades.

Symbolism of facades took a different meaning under modernism in the analogy between the façade and a narrative text was criticized under the term 'Romantic Falasy'. The evolution of modern architecture façade and a methodology to seek the truth, criticized the neo-classism and the previous trends in architecture as being 'an architecture of coatings', a piling up of materials; it is today the result of assemblages. Yesterday architecture was cut in stone today it is poured and molded, welded or riveted' (Ragon, 1969). In modernism the cultural message of facades became the sheer skin aesthetics of the glazed office façade, a puritanical flavour which irons out all irregularities and makes no concession to the senses, clean and shinning and casts no shadows, suggesting that technology will make the future life style perfectly untroubled and smooth. Antonio San'Elia in the Citta Nouva, 1914 wrote:' ***We must design and built the modern city in accordance with a new plan; it must be like a gigantic shipyard full of noise and movement and the modern house must be like an immense machine... The house of concrete, iron and glass, without sculpture or painted ornament, beautiful with the sole beauty'***

The international architecture was praised for internationalization of customs, of culture, of institutions, and of language. It was characterized as: *'the most grandiose phenomenon to have occurred in the development of human culture: the birth of a style common to all humanity, defined by stages based in natural laws and which consequently, will no longer be able to undergo involutions, but only evolve and come progressively closer to the immutable truth. The techniques of steel and concrete, give the façade an autonomy in relation to general structure of the edifice have brought about a real aesthetic revolution, free to play their own game. Being of merely an isolative nature the façade being light the windows broke away from their rectangular forms and facades became extensively or wholly glazed. Such transparency tends towards immateriality'* (Ragon 1969)

The liberty of the façade from its traditional role of bearing the ceiling, pushed architecture into two contradictory expressions, to symbolize immateriality, using extreme transparency, visually creating no barriers between the inside and outside, and the other towards massive brutalism of fortresses expressing a closed structures of which Frank Lloyd's Wright Guggenheim museum, and Paul Rodulf's laboratory is but an example.

The expression of technological achievements was a main concern and emphasis advocated for by the modern movement patrons. *'No longer are we concerned with nature, no longer are we concerned with transposing the wood of a tree trunk into marble, as the Greek did with their columns, nor with metamorphosing a forest into a cathedral, as the Gothic did, but what we have is a wholly new beauty, severe and cutting like a metal blade: the icy beauty of the computer'*(Ragon 1969). The technological expression would be regarded as the main driver for community ideological transformation and change. 'Bruno Taut exclaimed:' The city of today is a stone dessert which must completely disappear' while Adolf Behne claimed that the utilization of glass was not only for aesthetic reasons but for ethical reasons too:' *Glass architecture will eliminate the hardness in the hearts of Europeans and will replace it with gentleness, beauty and integrity. Glass is a pure material which matter has been melted. It is the most elementary of materials. It reflects the sky, the sun... Glass produces a superhuman effect'* (Ragon 1969). It is evident that pushing the utilization of technology to its limit was a means rather than an end for the modernists

It is interesting to note how this industrial expressionism gave way to higher exploitations of technology in building design materialized into the creations of 'hi tech' masters, leading to a critical interaction between architecture and technology. This interaction was further developed by the integration of computer modeling and environmental engineering modeling in to the building design process. Creating a new possibility of symbiosis between natural metaphors and physical building characteristics, among which where the performance of the building skin as Chameleon, or a polyvalent wall. High tech moved away from the arid expression of functionalism of the modernism era into a more sophisticated relationship with technology, embracing wider concerns over energy use, social responsiveness and ecological awareness. Terminology phasing out the 'hi tech' architecture into an echo-tech architecture appeared in literature (Slessor 2001), emphasizing the critical interaction between semi –independent disciplines into architectural design, such as building services and environmental control systems.

A building can only be regarded as successful if it reconciles aesthetic aspiration with a thoroughly worked out performance agenda. Reviewing the works of masters of the modernism indicate a rather simplistic view of the physical factors of the environment, confirming dichotomy between climate and architecture. Facades being dominated by the iconographic aspects of buildings (Fitch 1972)

The first half of this century witnessed a rapid growth in scientific discoveries that implicated architectural design in domains of material science, engineering science, building science, as well as behavioral science. The distinction between a design approach and a scientific approach was narrowed down based on the assumption that modern, industrial design is too complex for intuitive methods. (Willem, 1990) quotes: '***a relatively simple view of the design-science relationship is that, through the reliance of modern design upon scientific knowledge, through the application of scientific knowledge in practical tasks, design makes science visible***'. 'Aside from the automobile, the high-rise office building, whether tower, slab or block, is probably the most easily recognizable symbol of modernity worldwide. Modern building types among which the office building stands out, are generally the product of economic, social and technological forces beyond the architects' responsibility or power. Architects alone could not claim responsibility for the emergence of the new office towers as without the inventions of steel and mechanical elevators. While the economic factors that shaped the upwardly skyline was more shaped by a combination of central city land prices, corporate spatial needs, and engineering and mechanical ingenuity rather than aesthetic considerations' (Abel, 1997).

However, office plans were strictly dominated by building laws (distances of workers from natural light, and fresh air resources and allowable gross building area percentages, building heights) and cultural preferences of workplace arrangement and organizational management theories, prevailing at a certain time.
Regardless of region or culture, facades were using one language, stressing on expressionism and symbolism of the modern economic and corporate strength. It could be said that 'globalisation in architecture', is best described by office building facades.

The time for change in architectural demonstrations was clearly called for (Vale and Vale, 1991:14)*'As car design has moved from a concern with surface styling to a concentrated effort to improve engineering performance, so architecture needs to be similarly distant from its current concern with appearance only. It is time to stop putting the fins on the Cadillac'* In Europe there has been several successful attempts to embrace better energy performance for buildings by improving the performance and choice of building materials and the attendant technologies that service those buildings.

The symbolic analogy in building façade throughout their historical evolution is similar, to reflect not just available energy, cultural and behavioural ideology but political power and the cultural acceptance to that power. Facades also reflected commitment to a certain political ideology that may lead to the uncritical acceptance of the architecture expressing of that regime. The style then symbolises the system and so its assessment is fundamentally affected by whether the individual supports the ideology. Pure aesthetic judgment is permanently suspended (Smith, 1979).

The influence of the exterior façade configuration and its indoor psychological interaction will be discussed in detail later in this chapter as one of the major environmental psychology factors affecting the façade.

4.2.2 Facades as a behavioural manipulator:

Since the early 1970 Environmental psychology looked holistically at the person-in-environment as a system (Altman 1975; Altman and Rogoff 1987; Ittelson 1973; Werner and Altman 2000) . the relation between person and context is considered transactional. This approach is considered the main founding theoretical perspective for environmental psychology.
The main characteristic of this approach are(Bonnes and Bonaiuto 2002):

1. The person-in-environment provides the unit of analysis
2. Both person and environment dynamically define and transform each other over time as aspects of a unitary whole
3. Stability and change coexist continuously
4. The direction of change is emergent not pre-established
5. The changes that occur at one level affect the other levels, creating new person-in-environment configuration.

The basic assumption is to consider holistically to the complexity of human functioning in real life situation. It acknowledges the person context and the environmental context as well as the interrelations between them. This holistic systems oriented approach identifies the level of integration between the person and the environment. The concept assumes that the person is comprised of mutually defining physical/biological, psychological and scio-cultural aspects while the environment is comprised of mutually defining aspects, including the physical (natural and built), interpersonal (e.g. spouse and friends) and Scio-cultural (rules of home and community and culture). The person-in-environment system The holistic approach assumes that the person-in-environment system constructs objects of perception and thought thus contributing actively to the cognitive process. This approach asserts that reality is relative to the person's interpretations. Thus the holistic approach considers the context in both experienced and objective terms.

Proshansky and Fabian (1986), argue that the objective physical world and its properties has consequences on the behaviour and experience of the person quite often without his 'awareness. Under these circumstances, the individual can neither identify nor verbalise these influences, and indeed it is only by objective analysis of the 'external observer' that this influence of the physical environment on the person's behaviour and experience can be determined.

From studies of the context of office buildings in Cairo, it is seem that the modernism movement had a major influence on façade design ideology in Cairo. Modernism risked and destructed the association between the inside and outside of the building, which was in a profound sense the generator of facades throughout history. Modernism theory identified the ideal indoor environment for occupants in a technological deterministic manner. As this theory was criticized, no longer was environmental control perceived within narrow, quantitatively defined limits, nor was absolute environmental uniformity sought throughout the building. It is now acknowledged that a degree of thermal and visual diversity and a degree of occupant control may be preferable (Hawkes 1996). occupants' control is a relevant environmental psychological aspect that relates directly to facades configurations and therefore will be discussed extensively in this chapter.

4.3 Facades and Occupiers comfort and control:

Indoor thermal comfort and the technologies supporting are hailed as one of the finest achievements of modern civilizations. History tells us that enduring cold and heat discomfort has been the norm, a stimulus to develop systems for micro control. Building facades and roofs (building envelope) serve as a filter between the indoor and outdoor environments, as well as offering protection to its occupants from climate and privacy from intruders. The external climate is hard to change by architects or planners as it involves other buildings and landscapes owned by other owners or the government. The building envelope is seen as respondent to climate and people's expectations. However the degree upon which occupants perceive their indoor climate as comfortable depends on various variables that may be divided into **façade dependant and façade independent.**

Façade dependant variables are those variables that affect the indoor area adjacent to the façade configuration. These variables are **namely thermal comfort, visual comfort and delight, and noise control.** Climate responsive design is based on how the building form and structure moderates the indoor climate to achieve occupants' comfort. The pragmatic and physical laws associated with this aspect of architectural design are laws of science and climate characteristics (Hyde, 2000).

Facades independent variables are those related to **job stress and satisfaction,** which in an indirect way affect the occupants' perception of the workplace.

4.3.1 Thermal comfort

While the goal of achieving indoor comfort has profound implications on how buildings are designed and operated, facade configuration has an implication on the occupiers' perception of comfort within a space. Indoor thermal and visual comfort are continuously debated on grounds that traditional lifestyles in tropical and hot arid regions inspired a distinctive climate responsive architecture, where buildings were naturally ventilated and consumed less energy and were claimed to provide comfort.

The aim of undergoing a literature review on thermal comfort condition is to find out acceptable comfort conditions of indoor temperatures and humidity levels to minimize wastage of energy in unnecessary cooling of the building. The conclusion f this literature review will be used to determine the air-conditioning set points that will be used in simulation.

Following the oil embargo in the early seventies, attention given to building services was progressively being attacked from architects. The tradition of a long architectural profession without architects, and how these earlier buildings provided a perceived comfort for its occupants waned the confidence of architects in their own ability to deal with energy problems or opportunities for energy saving technologies. Traditional call for buildings to retain their traditional modes of inherited construction, location and orientation received publicity. Rather than calling for more efficient air-conditioning, the call was for abandonment of air-conditioning all-together, no matter if on the expense of the comfort of the modern user. If lightweight envelopes were poor insulators then the call was not for better insulation but for heavy weight structures in traditional masonry.

If the traditional ways of building are regarded the most appropriate way for providing thermal comfort, then it must not be forgotten that buildings always depend on active energy to attain comfort for its inhabitants. The human race at large has known from experience that an unaided structure is inadequately comfortable, Fires have been lit in the evening, oil-lamps were used, and in hot humid arid and humid climates muscle power was used for fans, and water for fountains for the heat of the day (Benham, 1984).

Controversy to this theory rises by studying the history and development of these building environmental controls. It brings up the question of why humans appear to be in a continuous quest for comfort? And why is the fact that energy was consumed to achieve comfort appear to be neglected in this argument?. Passive and active systems for providing cooling and heating systems have precedents in history. It is well documented how Romans used the hypocaust to heat their buildings, while in hot arid areas evaporative cooling was a common feature in building. Evaporative cooling was employed by an Assyrian merchant (c.3000BC), who had his servants spray water onto the walls and floor of his room. The Caliph Mahdi of Baghdad had a summer residence built with double walls between which snow was packed (Roberts, 1997). Olgyay (1957), argued that the first step towards environmental adjustment is a survey of climatic elements at a given location. Man is the fundamental measure in architecture and the shelter is designed to fulfil his biological needs, the second step is to evaluate each climate impact in Physiological terms. The third step is to apply the technological solution to each climate comfort problem. At a final stage these solutions should be combined in architectural unity.

Through trial and error attempts, achieving thermal comfort in buildings has been a historical quest. A wealth of research in this area dates back to the mid 19th century, but till the present day its definition remains fluid. This literature review starts by examining these definitions and the reasons behind the lack of a clear-cut explanation. The importance of achieving a thermally comfortable indoor climate is double fold, it is linked with productivity in office buildings, and active energy consumed in cooling/ heating systems in office buildings in hot arid climates.

'ASHRAE, 1992 and ISO 7330' define comfort as: 'a state of mind that expresses satisfaction with the thermal environment'. The *'state of mind'* from a strictly physical point of view is defined as when the brain consciously appears to reach conclusions about thermal comfort and discomfort from direct temperature and moisture sensations from skin, deep body temperatures, and the efforts necessary to regulate body temperatures. *'In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low and the physiological effort of regulation is minimized'* (ASHRAE, 1997). The definition still falls short of identifying the mental state, and the minimum physiological regulation as measurable identifiers. This state of mind may be a result of perceptual process, a state of knowledge or cognition, a general feeling or attitude, or a collective experience or judgement based on perceptions that may include thermal sensation, perceived air freshness, air motion, humidity levels (Hejis, 1994). (Humphreys, 1992) draws attention on the simplicity of this definition defining 'thermal comfort' as 'the absence of discomfort', expanding on the definition, thermal discomfort arises due to a wide ranging regulatory mechanism in operation that depends on a mesh of physiological, behavioural, and cultural aspects. (Givoni,1992) adds the factor of economy and available technology as a determinant variable towards estimating comfort /discomfort criteria. While (Fanger, 1982) explains human reaction to its thermal environment in terms of the heat balance equation, as a balance between the rate of production and loss of metabolic heat due to its exchange with the surrounding environment. It is concluded from evidence that achieving thermal comfort is a delicate and sophisticated matter that has not been fully understood, and is still debatable. This section seeks to find a range of indoor temperatures that would provide both a thermally pleasant environment while reducing cooling system energy consumption. Studies indicated that energy consumption is reduced by 10% for every 1C increase in air-conditioning set points. (Kimura, et al, 1994)

Thermal discomfort associated with exposure to warm and hot environments are attributed to the conscious awareness of perspiration and an elevated body temperature. Increasing air temperature will reduce convective and radiative losses and increases evaporative losses under sweating conditions. If air temperature rises above skin level or clothing surface temperature there will be a heat gain rather than a heat loss from the human body. When the heat loss by radiation and convection is insufficient to maintain thermal balance, the secretion of sweat onto the skin surface permits the dissipation of metabolic heat from the body by evaporation. The research undergone in the field correlates thermal environments with human responses in an attempt to enable a reliable prediction to define the range tolerable or pleasant conditions for indoor thermal comfort. Factors affecting thermal comfort can be divided into environmental factors controlled by designers and unpredictable, uncontrollable personal variables:

4.3.1.1 Environmental Variables:

Environmental variables namely air temperature (measured by dry bulb temperature, mean radiant temperature or dry resultant temperature), air velocity, and humidity. These variables are directly dependant on the design of building and it's heating and cooling systems.

Indoor Air temperature is defined as air that has no vapour content (ASHRAE, 1997) and is expressed as the dry bulb temperature within a space in Kelvin (K).

Mean radiant temperature (MRT): is defined as the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space. Mean radiant temperature varies throughout the enclosure unless the surface temperatures of all the internal surfaces of the enclosure are equal. (CIBSE, 1999). In literature Globe temperature is also used.

Dry Resultant temperature: It is equivalent to 'operative temperature' adopted for both ISO 7330 and ASHRAE Standards, at indoor speeds below $0.1\ m.s^{-1}$

Dry Resultant temperature is the average temperature of the indoor air temperature (t_{ai}) and the mean radiant temperature (t_r).

$$t_c = 0.5\, t_{ai} + 0.5 t_r$$

Table 1: (CIBSE, 1999) Recommendations for indoor comfort levels:

Offices (executive/ general/ open plan)					
Winter dry resultant temperatures For Sedentary occupation and clothing levels			Summer dry resultant temperatures For sedentary occupancy and clothing levels		
Temp	Activity	Clothing	Temp	Activity	Clothing
21-23 °C	1.2	0.85	24+/- 2 °C	1.2	0.7

Different temperature ranges are given for summer and winter, when the buildings are cooled or heated to account for seasonal clothing habits and chances to decrease energy consumption in buildings (Table 1).

Humidity:

The humidity in a room is expressed in absolute terms. Moisture content is the mass of water vapour per unit mass of dry air expressed in (kg.Kg $^{-1}$). Relative humidity is also used to express the ratio of vapour pressure at same dry bulb temperature, expressed as a percentage (%RH).

Both air temperature and relative humidity have been combined together to assess thermal comfort (Effective temperature indices). Results of ASHRAE studies reported by (Hutcheon, 1968) that at dry bulb temperatures of 25^{0}C there was no influence of relative humidity below 70% on comfort perception. While at 21.6^{0}C rated as slightly cool temperatures no effect of relative humidity was found below 90% RH (considered the threshold of the experiments). While at 27^{0}C slightly warmer temperatures than comfort temperatures the effect of relative humidity on decreasing comfort was recorded at 50% RH, and increasing above this level. These experiments indicated that humidity does not affect comfort unless indoor temperatures rise above comfort levels.

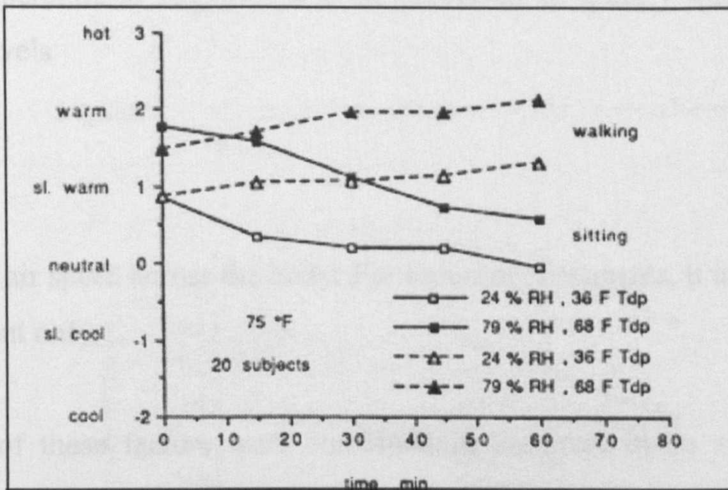


Figure 2: Thermal sensation at two levels of humidity from persons beginning walking or sitting continuously in 24oC room temperatures. Ref (Berglund L, 1994)

Berglund, (1994) through chamber studies concluded that indoor air is perceived to be fresher and less stuffy with decreased temperature (slightly cooler) and decreased humidity (Figure 2). The study emphasis that even with the slightly warmer indoor temperatures of 24^0C, and a low RH of 24% indoor comfort levels can hardly be maintained. This phenomenon is also described in ISSO 7730 indicating that a difference of 0.1 met is expected to produce a thermal sensation difference equivalent to decreasing air temperature by 1^0C. A difference of 0.4 met is expected to produce a sensation difference equivalent to 2.5-3 ^{0}C temperature difference. Therefore, for sedentary subjects, work by (Nevins, 1975) recommended that on the warm side of the comfort zone the relative humidity not exceed 60%.

However, the upper and lower limits of humidity levels are less precise. Low humidity is associated with comfort complains of skin dryness, and mucous surfaces, dry nose and throat, while increased humidity levels are associated with feelings of wetness and friction between fabric and skin. Studies examining the effect of air enthalpy on human perceived indoor air comfort (Fang *et al*, 1999) indicated that with increasing indoor air temperature and humidity, the air is perceived as less acceptable, and that thermal neutrality for occupants was reached at 23.5C/50% enthalpy. With exposure of 4.6 hours and an indoor thermal profile comprising 26C/60%RH, presented a clearly unacceptable perception of the indoor quality, with the decrease of humidity and air temperature to 23C/50% RH the perceived air quality was moving towards acceptable levels

Relative air speed:

The net mean air speed across the body. For sedentary occupants, it is taken as the room air movement only.

One or two of these factors were combined in literature in an attempt to produce a single index that would adequately describe some or all of the significant conditions that affect thermal comfort these attempts may be classified under four different categories that could finally be assessed as interlinked classes of research. Thermal scales and comfort charts must be studied carefully to estimate their suitability for hot arid regions. (Givoni, 1992) discusses the effect of using Olgyuy's bioclimatic chart and the modifications that were needed for a hot arid climate. He argued that adopting the bio-climatic charts suggests ventilation during daytime, which would elevate the indoor temperature and result in excessive heat storage in the building mass. He argues that the best strategy is to close the building during daytime and ventilate it only during the night hours if still air conditions (air speed below 0.2 m/s) is to be maintained. If higher air speeds are adopted 2m/s the flow of air through a building extends the upper limits of acceptable humidity and temperatures. In this case, the indoor air and surfaces follow closely the ambient temperatures. Therefore even in this scenario, allowing day time ventilation can only be experienced when outdoor temperatures are within an acceptable comfort range and higher indoor air speeds could be maintained without introducing pollution or noise to the indoor space. However, although closing up the building by shutters during daytime is applicable in residential buildings when most occupants leave the house for their work, is debatable for the workplace. Closing up shutters during day time may reduce the indoor gains from direct ventilation and obstruct direct solar gains but would trap the indoor thermal gains from people, machinery and lighting, and obstruct the view out. The use of natural ventilation in light of the previous argument is unattainable in hot arid areas especially in the summer season.

Physical variables have been used either separately or collectively in an attempt to identify thermal comfort temperatures ranges in buildings.

(Brager and de Dear, 1998) through an extensive literature review classified thermal comfort research into three classes depending on four variables: complexities of the instrumentation used to examine the physical variables, the time span upon which subjects were examined, the setting of experiments (laboratory or real life situations) and the variables included in the resultant thermal equation. There classification includes:

Class III: Where the major band of research from the nineteenth century till the early 1970 lies. This type of research is based on asynchronous measurements of room temperatures and subjective questionnaire analysis. Earlier thermal indices and models are found in this class. The quality of the resulting data does not allow explanatory analysis expect for research questions requiring simplified statistical techniques.

Class II: where climate chamber experiments in which all physical environmental variables necessary for the heat balance equation were taken into consideration (such as outdoor temperature, relative humidity, air speed, clothing, and metabolic rates.). The physical data was collected at the same time as questionnaires were administered. The widely acknowledged indices from this set of data include the two nodal model PMV/PPD indices[2]. These indices allow for assessment of the main physical parameters affecting comfort while accounting for behavioural adjustments and subjective responses and control. These types of results were criticized on basis of their subjectivity. Canter and Stringer, (1975) argued that when subjects are asked to respond to any kind of environmental stimulus, this brings about a degree of awareness which does not exist in everyday life. (de Dear, and Brager 2001) argued that the controlled atmosphere of the chambers and the treatment of the occupiers as passive elements of the experiments, without allowing them behavioural adjustments, or accounting for physiological responses, and the assumption that thermal comfort is

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[2] PMV is the Predicted mean vote, is a simple numeric scale (Fanger,1982) to designate thermal comfort between -3 and +3 (-3 cold, -2 cool, -1 slightly cool, 0 neutral , +1 slightly warm, +2 warm, +3 hot)

PPD is the Predicted Percentage Dissatisfaction: The symmetrical PPD distribution is expressed as a function of the Predicted Mean Vote. When PMV is zero, PPD is 5% – meaning that even under the best conditions, not everyone is satisfied with the condition of mean neutrality (refer to Figure 3, Chapter Four).

universal is all types of buildings and climates needed to be addressed critically by further research..

Class I: Includes all field experiments in which laboratory grade testing equipments are used along a longitudinal survey of different types of buildings in different climates. Measurements are more compressive than the previous two classes (at 0.1,0.6 and 1.2m heights) and allows for careful examination of non-uniformities in the environment. This type of research along side Class II research has constantly been feeding into ASHRAE comfort standards and ISO 7330. Researchers debated on the possibility validating chamber results by actual fieldwork (Humphreys,1976) 1994). Studies reinforcing this direction in research were funded, such as ASHRAE sponsored work in San Francisco USA, Baulder Australia In the late 1980's due to the advancements in computer analytical software and its capabilities in data storage, studies of thermal comfort were based on large statistical samples for occupants (giving detailed reports on their thermal sensation, activity and clothing) incorporating laboratory grade instruments to take accurate measurements of the physical variables. (Schiller et al, 1988) and (De Dear et all, 1993) studied the thermal environments and comfort in office buildings. (Dorgan, 1994) analysed 50,000 office buildings and results were classified as healthy buildings meeting standards always, most of the occupied hours, or unhealthy failing to meet standards. (Federspiel, 1998) analysed complaints from 23,500 occupants in 690 buildings and concluded that most complaints (77%) were concerning the environmental conditions being (hot or cold). However, the results of this type of research was constantly referring and comparing its finding to the class II type of research. Results of this type of research aimed at increasing understanding of the human comfort zone in naturally ventilated buildings as opposed to air-conditioned buildings. In conclusion, these research outputs emphasised the notion that people regardless of age or culture share the same thermal comfort range of temperatures. The second output is the need to keep office building occupants on the lower limit of thermal comfort ranges in cooling conditions to maintain both thermal satisfaction and productivity levels.

However a Class IV: based on the previous three classes, includes the use of thermal manikins and human body simulation tools. Thermal manikins are still under-development in a trial to simulate the complex and dynamic human thermoregulatory systems (such a s blood flow and skin thermo receptors) (Huizenga et al, 2001).

Researchers developing manikins intend to decrease time spent on surveys and in climate chambers. This class of research is still controversial and needs to be validated with Class III type of research.

The difficulty in determining indoor conditions also lies in the length of exposure to these environmental factors.

4.3.1.2 Personal Variables

Occupants adapt to the personal variables by adopting three measures: **Behavioural adjustment, Physiological adaptation and psychological expectations.**

Behavioural adaptation is classified into three domains (Brager and de Dear, 1998) into personal, environmental and cultural adjustments

Personal adjustments includes all personal modifications undergone consciously or unconsciously to modify the body's heat balance with its surroundings. These modifications are classified into metabolic, environmental, and cultural modifications.

Changing the metabolic rate is when the body modifies its internal heat generation by decreasing/increasing activity or body heat loss/ gain by decreasing/increasing clothing, changing posture, eating or drinking. Activity levels are used to predict the metabolic rates for specific activities. These assumptions consider that occupiers perform a number of activities that are frequent and take place alternatively per hour. Therefore the average metabolic rate is indicated within tables (ex. for office occupants it is predicted that activities of typing, filing and walking take effect hourly and upon this assumption the metabolic rate presented in met is established. (CIBSE Guide A). The complexity of setting exact values for these personal variables lies in the adaptive measures and control available for building occupants, which in turn explains the fluidity of the thermal comfort definition.

Environmental adjustments occurs when occupants engage actively in modifying their surroundings or using controls to open/shut windows or vents to regulate indoor temperatures till they achieve a perceived state of thermal comfort or moving to a different thermal environment.

Cultural adjustments occur when occupants schedule their activities (siesta) or adopt certain dress codes. Clothing is a personal variable that depends on the seasons of the year and fashion. Clothing provides insulation to the exchange of heat between the body and its surrounding environment. Clothing insulation provided by an individual garment consists of the effective resistance of the material from which the garment is made plus the thermal resistance of the air layer trapped between the clothing and the skin (CIBSE Guide A)

However, various factors acts as constraints to this adaptation method such as the wealth of the occupants, the cost of fuel, the cost of clothes, socially correct dress.

Physiological adaptation (acclimatization) affects body thermoregulation set points of the autonomic nervous system, which in return leads to changes in the body physiological response to decrease the strain induced by the exposure to these environmental factors. However advances in Physiological studies indicated that humans have no heat flux sensors but only thermal sensors or receptors. Cold receptors are more sensitive than warm receptors in sensing temperature fluctuations (Benzinger, 1979). The primary response for heat stress in hot arid climates occurs when the body undergoes circulatory regulation (increase heart rate and vaso-dialation to increase blood flow under skin), dropping skin temperature, and sweat rate increase to lower the higher core (body) temperature (Klausen, 1967,Givoni, 1976). Higher body temperature triggers sweating which in turn would increase tolerance to warmer conditions, however literature suggests that such acclimatization does not play a strong role in subjective thermal preferences across the moderate range of activities or thermal activities present in most buildings. Body thermal comfort is retained with uniform skin temperature about 33^{0}C and skin wetness <25% above these levels discomfort occurs (Berglund, 1994). Acclimatization by sweating does not play a strong role in subjective preferences across the moderate range of activities and indoor thermal conditions. (Brager and de Dear, 2000), the mere occurrence of sweating is associated with wetness, which increases the friction between skin and fabric, and the release of body odours, which is perceived as discomfort and unpleasantness.

Another Physiological effect is the decrease in oxygen intake that is related to the insufficient blood supply to the working muscles caused by an increase of the cutaneous blood flow (Klausen, 1967). These findings were acknowledged with climate chamber analysis on five Saudi subjects (Haboubi, 1996) under 17C, 33and 46^{0}C and 68% RH and results reported an increased heart rate from 131.2,138.8, 156.4 heart beats (HR) respectively and a decrease of oxygen intake. A decrease in oxygen intake has been linked to the decrease of cognitive, attention, long-term memory and working memory abilities of the brain (Moss *et al*, 1998). It can be argued that the reduced oxygen intake in subjects experiencing harsh hot and arid climates may give way to decreased concentration, tiredness and a decrease of the metabolic rate leading to a final decrease in productivity. This argument on its own justifies the need for air conditioning systems in buildings where building design has failed to moderate the climate to an acceptable thermal comfort level.

Psychological expectations is a major factor in understanding thermal performance in buildings. Psychological expectations are defined by (McIntyre, 91) as ' A persons reaction to a temperature which is less than perfect will depend on this persons expectations, personality and what he is doing at the time.' (Fountain *et al*, 1998) states that factors beyond physics and physiology play an important role in building occupants' expectations and thermal preferences. Only a match between a person's expectations about indoor climate in a particular context and what actually exists can result in satisfaction and acceptability of the thermal sensation.

It is claimed that the availability of indoor climate control are responsible for changing people psychological expectations. (Ruck, 1989) analysed several laboratory and field studies undergone over a time span of 5 decades in the UK environment and stated that between the 1930s and the 1970s, there has been a shift in thermal comfort requirements upwards (to more warmer conditions in winter).

Table 2: Trends in Neutralities at light activities

Laboratory United States			
Year:	1923	1941	1966
Authors:	Houghten and Yagloglou (1923)	ASHRAE (1968)	Nevins et al (1966)
Ta	18	21	22.5
Field Studies united Kingdom			
Year	1936	1954	1978
Sample	light industry	office workers	office workers
Authors	Bedford (1936)	Black (1954)	Fishman and Pimbert (1979)
Ta	18	20	22

The shift in thermal neutrality (Table 2), represented social and technological changes such changes in fashion, building with lighter weight materials and considerable microclimatic adjustment through active energy use.

(Givoni, 1992) Classifies two comfort temperatures ranges according to the countries economic status (developed and developing). Thought the classification is not clear in terms of income or standard of living. This work relates economic status to acceptance of comfort in still air conditions. However, the studies conclusions did not differentiate between the building use, or occupation hours or the length of the exposure time, therefore its conclusions were excluded.

Fanger and Toftum, (2002) through experiments indicated the increased level of occupants' thermal expectation in air conditioned buildings, they suggested an expectancy factor to an extension of the PMV model for its application for warm environments. The expectancy factor varies between 1 and 0.5. It is 1 for air-conditioned buildings. For non-air conditioned buildings, the expectancy factor is assumed to depend on the duration of the warm weather over the year and the common use of air conditioning in the surrounding region (Table 3and Table 4). It is also worthwhile to add to this assumption the common use of air-conditioning in the occupants' daily life while performing other activities such as driving/ at home or in leisure.

Table 3: Expectancy factors for non air conditioned buildings in warm climates

Expectation	Classification of location of non-air-conditioned buildings	Warm period	Expectancy factor
High	In regions where air-conditioned buildings are common	Occurring briefly during the summer season	0.9-1.0
Moderate	In regions with some air-conditioned buildings	Summer season	0.7-0.9
Low	In regions with few air-conditioned buildings	All seasons	0.5-0.7

Ref: (Fanger and Toftum 2002)

This prediction translated into upper limits of operative temperatures allowable for the comfort zone in non-air conditioned buildings in warm climates under a metabolic rate of 1 met, clothing insulation of 0.5 clo, an air velocity of 0.3m/s, and a relative humidity of 70%.

Table 4:Upper temperature limits of comfort zone adjusted for expectation in non-air conditioned buildings in warm climates

Expectancy factor	PPD%	Upper operative temperature limit
1	10	27.9
	20	28.7
0.7	10	28.3
	20	29.4
0.5	10	29
	20	30.5

Ref: (Fanger and Toftum 2002)

The previous studies indicating occupants' raised expectations of thermal comfort and the decreasing tolerance to varying indoor temperatures were emphasized by surveys carried out on existing building occupants'.

In a survey conducted after two years of initial occupations on a low energy hybrid naturally ventilated office building (Parine and Peplow, 1999). The survey indicated that despite the original design intentions, the building occupants demand a neutral temperature similar to a fully air conditioned building and not a naturally ventilated one. In this project occupants contributed by voting and participated with architects in discussions while the building was being conceived Though the intentions of natural ventilation and operable windows was based on the existing workforce vote, but the survey indicated that occupants opted for higher indoor temperature and that they preferred to wear light clothing in winter. The Building management received complaints of the building being too cold and so the mechanical system set point was raised to 24.5C. The survey indicated that 48% of the occupants felt that ventilation through natural ventilation was ineffective, as the open floor configuration of the building made it necessary to for all workers to agree on opening or shutting windows, which in practice proved difficult.

(Cena, 1994) reported that during an initial survey a free running building using fans to circulate the air, in Perth-Australia. Although the temperatures were around 27^0C and peaked at 34^0C, office respondents ranked air temperature in fifth position after lighting, air quality, office furniture and comfort of chairs as the most important attributes towards a satisfactory work place. However after one season where air conditioning was installed the same respondents changed their original opinion and without any exceptions reported that air-conditioning is an indispensable part of the office environment. Similar findings were reported by (de Dear and Aliciems, 1988) concluded that occupants of free running buildings preferred not having air-conditioning and tolerated a wider range of temperatures while air-conditioned building occupants regarded air conditioning as essential. These studies concluded that relativity of the thermal perception affected the overall impression of warmth, and is dissociated from the actual microclimatic conditions prevailing in buildings.

However to condemn the increasing demand for air-conditioning on basis of thermal comfort expectations alone is not justified, the link between the productivity levels and thermal comfort due to the utilization of air conditioning is not thoroughly investigated in these studies. Further studies needs to look at this particular link that might have a strong influence on the reported changing perception of occupants' thermal comfort.

However (de Dear and Brager, 2001) argues that air conditioning/ heating systems seems to be driving expectancies to a narrower range of thermal comfort zone, and less tolerance to thermal deviations from these conditions. There research advocated for allowing adaptive controls to the occupants, which in return would increase thermal comfort ranges and decrease the active energy consumption used for these building services systems.

4.3.1.3 Thermal Comfort temperatures ranges in hot arid regions:

A wealth of research exists on thermal comfort in different climates; which constitutes a valuable contribution towards understanding occupants' thermoregulatory systems as well as their psychological expectancies. However, these research recommendations and conclusions are still premature and provide limited answers to personal and environmental variables. Although several studies on the hot arid regions have claimed that thermal tolerance is higher than European standards, the increasing use of air conditioning systems in hot arid areas needs to be understood and justified.

It is also notable that thermal comfort indoor is assessed differently than thermal comfort outdoors. While it is true that people spend their vacations in hot climates by the beaches, or in winter skiing in very cold conditions in deliberately sought after locations where thermal comfort conditions rates off the known scales. (Potter and de Dear, 2000). The research concluded that thermal sensation outdoors is perceived differently than indoors and that comfort standards are not applicable in outdoor settings. This endurance maybe attributed to the short exposure period to these conditions and the personal freedom to change his environment by moving to another location or increase/decrease metabolic rates and clothing insulation.

The adjustments that people can manipulate on their posture or clothing are not always applicable in the case of an office environment. Office occupants' dressing style is constrained by certain social habits and dressing codes. Exposure to environmental conditions becomes a critical criterion as occupants are assessed to spend more than 90% of their time indoors in summer and 96% of their time indoors in winter (Leech et al, 2000).

Research in the field of thermal comfort identifies two sets of comfort zones in accordance to the building services and envelope design. Thermal comfort is therefore divided into thermal comfort for air-conditioned buildings and Thermal comfort for naturally ventilated buildings. The following section discusses the two sets of variables and the possibility of their utilization for buildings using hybrid-cooling systems in hot arid areas.

The Constancy Theory:

Design of air conditioned buildings is based on assumptions of steady state equilibrium the human body and its surrounding as recommended by ASHRAE standards 55, CIBSE Guide A, and ISO 7730. These standards are based on the heat balance equation (Fanger's equation) for thermal comfort. Fanger's equation is used for environmentally controlled buildings and is dubbed by researchers advocating adaptive opportunities in building as the constancy theory (explained in the adaptive theory later in this text). The comfort equation relates the four physical variables of the thermal environment namely air temperature surrounding the body; mean radiant temperature, partial water vapour pressure in the air surrounding the body (Pa) and air speed with two personal variables of metabolic rate and clothing insulation (surface temperature of clothing and the ratio of the clothed area to unclothed human body). These variables are combined into a single value represented on a thermal sensation scale. Using Fanger's thermal comfort equation a Predicted Mean Vote (PMV) indices, and Predicted Percentage Dissatisfaction (PPD) indices were proposed.

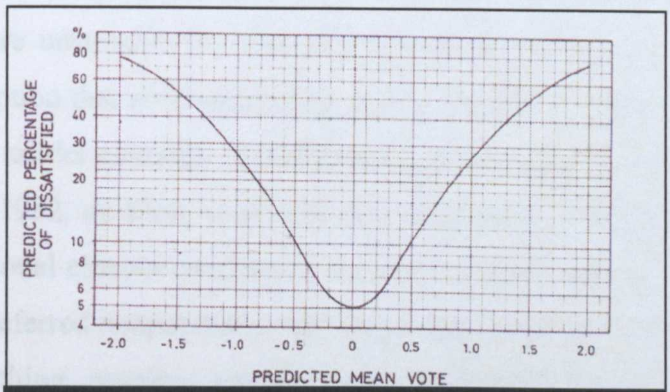


Figure 0:Thermal sensation curve. (Fanger,1982)

Fanger's curve (Figure 0), illustrates that dissatisfaction with the thermal environment increases rapidly as temperatures deviate from the optimum conditions. The curve explains the necessity of maintaining close control over the temperature of a multi-occupied space, even though an individual can still sustain a fairly flexible response to regulate his/her personal thermal comfort. Sharper dissatisfaction with indoor thermal conditions are predicted when the mean vote deviates to cooler or warmer sensations, and therefore it is recommended to work with the range of +/- 0.5 PMV.

The PMV can be calculated for different combinations of metabolic rates, clothing air temperatures, air velocity and air humidity. Comfortable levels may be achieved by iteration. However the equation has its boundaries. The PMV is derived from a steady state model, it can be provided during minor fluctuations of one or two variables. It is recommended to use the index between –2 and +2 votes, and limit its six parameters between

- Metabolic rates = 46 W/m^2 to 232 W/m^2 (0.8 met to 4 met)
- Clothing between 0clo to 2clo
- Air temperatures between 10 ^{0}C-30 ^{0}C
- Mean radiant temperatures between 10^{0}C to 40^{0}C
- Air velocity between 0m/s to 1m/s
- *And humidity levels between 30%-70%*

The index considers air temperatures above 30 ^{0}C as harsh climates that causes heat stress and are unsuitable for attaining human performance in work Therefore there is an assumption that air-conditioning will be used for the same thermal comfort levels attained in milder climates. It is claimed that the equation could be universally applied, (Fanger 1982, de Dear et al.1999 and Busch 1992) reached the conclusion that although regional climate conditions, living conditions, and culture differ widely worldwide, the preferred temperatures that people identified as comfortable under like conditions of clothing, activity, humidity and air movement were similar. Studies surveyed by (Fanger, 1982) included minor differences in comfortable temperatures between men and women and age groups, it was concluded that the present experiments show no significant differences in comfort conditions between male and females, or age groups, and if any differences do exist it is small and of no engineering significance. These standards are widely used to provide comfort for the largest portion of office occupants (80%), throughout the occupied space by maintaining uniform steady state conditions that vary within a controlled variation of temperatures +/- 1.5 ^{0}C and a metabolic rate of 1.2 met under a steady state assumption.

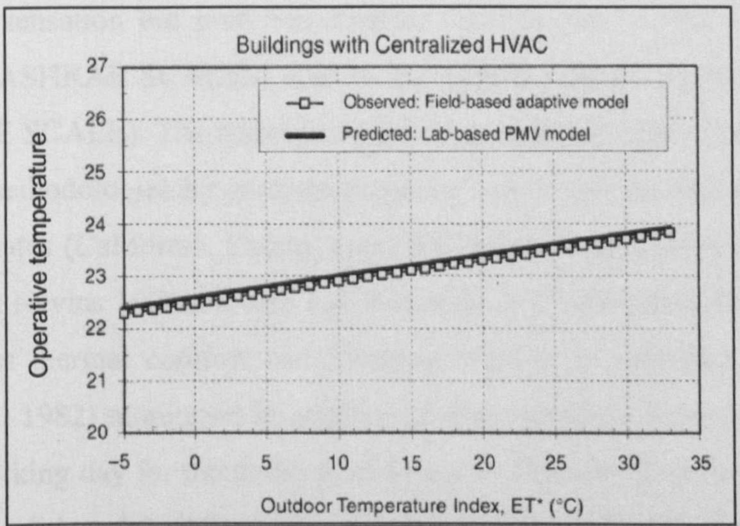


Figure 4: Observed and predicted thermal sensations (Brager and de Dear 2001)

Figure 4, is used as a tool to assess thermal comfort in environmentally controlled buildings (McIntyre, 1982, Brager and de Dear 2001). The relation between the effective outdoor temperatures (ET) to operative temperature indoor indicates that the HVAC system should maintain indoor operative temperatures between 220C to 240C.

In this context thermal indices aims at providing thermal neutrality for building occupants. 'Thermal Neutrality' is defined as the situation in which people describe themselves as neither cool nor warm'. (CIBSE Guide A, 1999) defines thermal neutrality as the optimal temperatures for any combination of activity, clothing and environmental parameters

However, fieldwork on thermal comfort indicated that neutrality in hot arid climates in air-conditioned buildings is different from preferred temperatures. (Cena and de Dear, 1998) in a hot arid region indicating that work place occupants' thermal neutrality in an air conditioned building occurred at 23.3C in summer and 20.3 C in winter but preferred temperatures were 22.2 C for both seasons (at the cooler side of thermal neutrality in summer and the warmer side in winter).

Brager et al, (1994) hypothesized that in summer people preferred to feel neutral thermal sensation but preferred thermal comfort was on the cooler side in summer (-1 on ASHRAE SCALES) and on the warmer side of neutrality in winter (+1 on ASHRAE SCALE). The research studied and analysed eight field studies that had consistent methodologies for analysing summer and winter thermal sensations but in different climates (California, Connecticut, Britain and Thailand by (Schiller *et al* 1998,Gagge and Nevins 1976, Howell and Kennedy 1979, McIntyre 1980and Busch 1990). To assess thermal comfort conditions in relation to operative temperatures (Fisherman et al, 1982) monitored 26 subjects in their actual workplace environment throughout a working day for the duration of a year in The UK. Results indicated that people in air-conditioned buildings had minor tolerance to indoor variations. The study used Mean radiant temperature indices and compared monitored results of discomfort in comparison with Fanger's thermal comfort equation. Results indicated that above 24^0C subjects reacted strongly and registered their disapproval. Thus in real life situations people are more critical of uncomfortable conditions than predictions based on artificial climates suggests.

(Barger and de Dear, 2000) through their studies and analysis of 21,000 sets of raw data compiled from previous field experiments in 160 office buildings worldwide indicated that occupants in both naturally ventilated and air-conditioned buildings had the same neutral thermal comfort range of temperatures, but the preferred temperatures differed between occupants of the two building types (Figure 5). The study investigated the preferred temperatures in both types of buildings and concluded that occupants of air conditioned buildings preferred the indoor temperatures lower in summer and warmer in winter by 1^0C than neutral temperatures while naturally ventilated building occupants preferred temperatures following track of the outdoor weather profiles. The study concluded that the more thermal comfort is provided to occupants the more their demands increase which creates an increased demand for energy utilized in the cooling systems and heating systems.

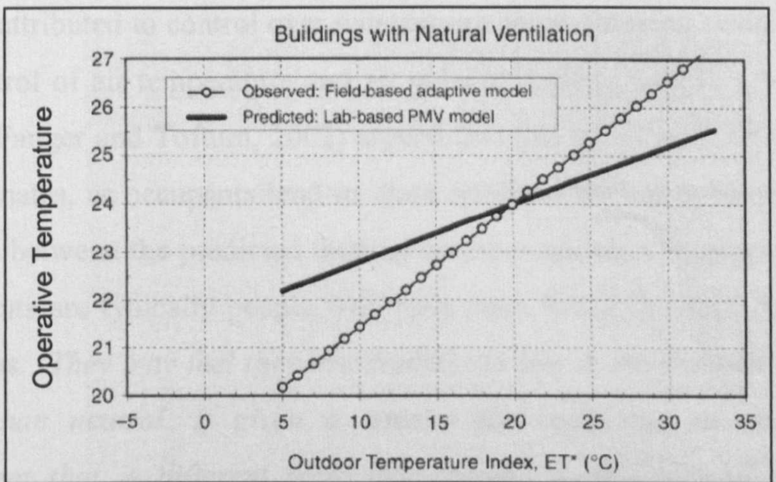


Figure 5: indicates differences between the PMV model and field observations (Brager and de Dear, 2001)

The Adaptive Theory:

Laboratory based thermal comfort standards and predictive models that are used to determine acceptability of operating conditions for maintaining indoor thermal comfort were continuously challenged. These challenges were based on the research findings that occupants in real life experienced thermal sensations different than those predicted by Fanger. Larger research samples and field studies were required.

An alternative to conventional thermal comfort theory that assumes that occupants are passive elements in their indoor environment is the thermal adaptation theory based on work by (Aliciems, Nicol and Humphreys), their work indicated that in hot arid areas people were found to endure and tolerate higher temperatures than suggested by the PMV model. Thermal adaptation theory embraces the notion that office occupants need to have control over their indoor thermal conditions and that occupants adapt to it by modifying their own behaviour, or gradually adapt their expectations to match the thermal environment. This theory is built upon allowing people greater control over their environment and allowing temperatures to closely track patterns in outdoor climate. This theory is envisaged to increase comfort in office buildings while reducing energy consumption.

Milne G., (1995) and Fanger and Toftum, (2002), contested that the divergence between people thermal preferences and acceptable thermal conditions between naturally ventilated buildings in hot climates and in air conditioned buildings is merely attributed to control over window openings. Opening windows may provide some control of air temperature and air velocity only to people who are near to the facades. (Fanger and Toftum, 2002) argued that this is not an acceptable explanation in hot climates, as occupants tend to close windows during daytime. But related the difference between the predicted thermal comfort models to occupants' expectations, as occupants are typically people who have been living in warm environments over generations. '*They may feel they are destined to live in environments where they feel warmer than neutral. If given a chance they may not on average prefer an environment that is different from that chosen by people who are used to air-conditioned buildings*'.

Results of founding studies of thermal comfort in hot arid areas were based on small samples. (Nicol, 1975) studied thermal comfort on lightly dressed subjects on seven subjects in Roorkee in India and nine in Baghdad to assess their thermal sensation within a globe temperature ranging from 32^0C-40^0C. His study concluded that thermal sensations were strongly related to the globe temperature and not to the humidity levels, which were low. His study stated that: '*these lightly clad acclimatised subjects found least discomfort at 32^0C (globe temperature), provided air-movement exceeded 0.25m/s. The control of air movement had a significant role in achieving thermal comfort.*' Results of this research stated that subjects in hot arid climates were thermally comfortable at higher temperatures than British office workers who found thermal comfort between 20-25 C. But the results are not reliable, as they did not test the subjects in the hot arid areas for the same temperature ranges and clothing insulation as that of the British subjects. (Humphreys, 1976) extended his studies of thermal comfort by comparative analyses of studies done over a range of 18 countries (including Nicol's studies) with different climates and different building user sets. The study concluded that the preferred thermal comfort temperature was related to the average outside temperature and that as outside temperature increased so did the preferred temperature.

The study derived a thermal comfort regression equation that predicts neutral temperatures in relation to the mean temperatures (Figure 6).

T_n=2.6+0.831 T_m

T_n is the neutral temperature and T_m is the mean temperature.

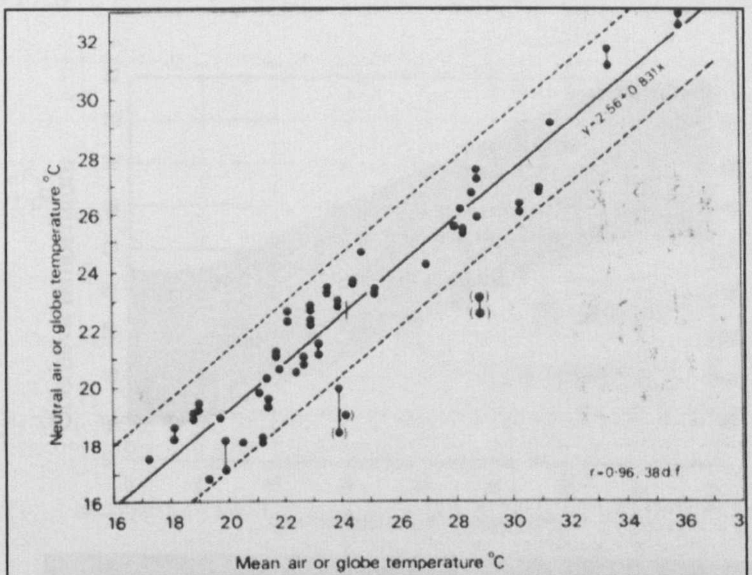


Figure 6: Globe temperatures and thermal comfort (Humphreys, 1976)

Although these graphs indicate that people's thermal comfort and neutral temperatures is in relation to the outdoor temperatures. But (Humphreys, 1994) concluded that if people are accustomed to a certain level of comfort and expectations, then these charts may not apply and a close understanding of expectations must also be considered in assessing people's needs.

As a result Humphrey's equation and graph are not applied to all outdoor temperatures. However restricted results to the research, similar in nature to those applied by Fanger were derived. The research proposed an index for assessing thermal comfort and suggested that summertime temperatures in office buildings to give a mean thermal comfort air temperature of 23^0C and a peak of 25^0C would render it an acceptable indoor environment. (De Dear and Brager, 2001) Based on field studies of thermal comfort of a large sample of 21,000 sets of raw data and 160 building located in four continents, proposed a variable temperature standard to encourage hybrid ventilation for bioclimatic architectural approaches. There equations stated that Comfort temperatures of up to 32^0C could be governed by the equation (Figure 6).

Optimum Comfort temperature (C^0)= 0.31 (mean outdoor monthly air temperature)+17.8

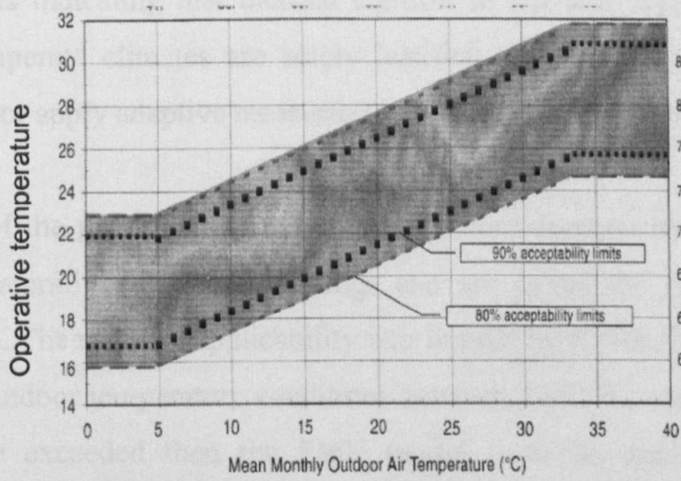


Figure 7: Adaptive theory ranges of indoor temperatures, source (Brager and de Dear, 2000)

(Brager and de Dear, 2000, Brager and de Dear, 2001), in (Figure 7), recommend that operative temperature be limited to 27.7 ^0C especially in extreme outside weather conditions are above. Above a mean ambient temperature of 32 ^0C, the application of the equation is restricted where the lines of the graph should not be extrapolated but a flattening, or by adopting the higher limits of the to 90% acceptability. However, this operative temperature is slightly higher than recommendations by CIBSE in Table 1 in this chapter. The study did not provide insight on acceptable exposure time to these higher limits of indoor thermal conditions. The other un-addressed concern in these recommendations is that these results for naturally ventilated buildings though revealing higher tolerance for indoor temperatures do not indicate the effect on productivity levels in these buildings. These types of study were only concerned with the possibility of decreasing energy consumption of building services while depending on human regulatory systems and adaptive measures to regulate the occupants' thermal comfort. These studies accused occupants of air-conditioned buildings of raising their thermal expectations, and developing high expectations for homogeneity and becoming critical if thermal expectations are not met. However, these studies ignored other studies on the sensation of freshness and the effect of controlled cooler temperatures in office buildings and its link to increasing or decreasing productivity. It is also important to note that if the lower lines of acceptability levels were adopted in design of systems they reveal a similar thermal response from occupants to those in air conditioned buildings. Results indicating that thermal comfort in hot arid regions has a higher margin than temperate climates are solely justified on the ability of occupiers to manifest control or apply adaptive measures to their thermal environments.

Results of the previous research are under consideration by ASHRAE to be used for only naturally ventilated buildings and are called the Adaptive Comfort Standards (ACS). The research applicability was limited by ASHRAE deliberations to be confined to outdoor temperature conditions between 10-33^{0}C, and if these outdoor temperatures are exceeded then the PMV model is to be used, which requires significant cooler indoor temperatures (De Dear and Brager, 2002). This is a major concern in hot arid climates where mean outdoor temperatures during working hours during the summer period from May till August exceeds those limits. A clear conflict arises in dealing with occupants' expectations. A hybrid system in the harsh summer climate becomes a major risk as occupants' expectations in the case of hot arid areas will have to shift on daily basis between natural ventilation and air-conditioning thermal tolerances. Literature has indicated the impossibility of extending tolerances of occupants' used to air-conditioned systems to those of naturally ventilated buildings.

This brings up the question on the acceptable range of indoor operative temperatures, tolerance and acceptability of thermal conditions in relation to productivity levels in hot arid areas. However, the argument arises that hot arid climates from a human thermal comfort point of view are considered harsh climates, and this argument does not take on board that the global nature of doing business requires alert, active, productive building occupants regardless of their climatic zone. Historical habits used to acclimatize to the weather by using adaptive measures such as reducing activity levels (Siesta in peak hot evening times), or reducing clothing values (met), may not be appropriate to sustain within a 9-5 working day requirement in hot arid areas.

4.3.1.4 Thermal comfort and natural ventilation:

In hot dry areas ventilation must be carefully planned, as introducing large quantities of hot air will lessen the advantages from thermal regulation of the massive weight construction of the building. Thermal conditions in hot dry lands indicate that windows should not exceed the minimal size consistent with the need for good day lighting. If large openings are required then they must be shut during the day to help keep out hot air dust sand and flies (Givoni, 1994).

The effectiveness of building ventilation has a significant effect on the performance of office occupants. Poor indoor quality impairs the performance of employees. It has been estimated that design, build and operating costs are in the ratio of 1:5:200. Poor standards of building ventilation can have a significant impact on office employees' performance (Evans, 1998).

When a building is cross-ventilated during the daytime the temperature of the indoor air and surfaces closely follow the ambient temperature. Therefore, it is only possible to achieve comfort by daytime ventilation only when indoor comfort can be experienced at the outdoor air temperature (Givoni, 1994). During summer in a hot dry climate it is both desirable and possible to lower the indoor temperature significantly below the outdoor level during the daytime hours by minimizing the heat gain from the outdoor air. To this end the building should be compact- The surface area of its external envelope should be as small as possible to minimize the heat flow inside the building. The ventilation rate should be kept to a minimum required for health.

Ventilation is critical to indoor air quality and energy costs associated with the choice of the building ventilation system is a major operational concern. In industrialized countries, the focus shifted towards improving the standards concerned with energy recovery systems rather than reducing building operational costs by limiting outdoor air intake to mechanically controlled buildings.
The Ventilation air cannot remove air from the office building during the day unless the building is hotter inside than outside, and that is against the comfort strategy. Ventilation in the morning in Cairo context is also arguable as pollution levels outdoors are high and dust storms create an added problem.

In hot arid areas, solar radiation increases the temperature of sunlit surfaces by as much as 16-44C and accelerates heat flow into structure. The effect of shading a sunlit external surface is to bring its temperature much closer to that of shaded air: the smaller outdoor-indoor temperature difference means that less heat will be driven inwards. If the effect of solar radiation through glazing is ignored, the heat gain from the walls of a normal building does not comprise a large percentage of the total gain of the shell as a whole (Sinai, 1980).

Although the window to wall ratio would have a general effect on building thermal comfort, it has a localized thermal effect that affects body thermal balance.

Radiant temperature asymmetry is defined as: 'the plane radiant temperatures on opposite sides of the human body. The plane radiant temperature is the radiant temperature resulting from surfaces on one side of a notional plane passing through the point or body under consideration' (Fanger *et al*, 1980).

Radiant temperature Asymmetry is caused by three localized effects in relation to the position of occupants within the space. These effects are local cooling (radiation exchange with cold surface such as glazing), local heating (radiation exchange with warm surfaces (warm walls, radiators) or intrusion of short wave radiation (direct solar transmission through glazing). It is recommended that dissatisfaction due to thermal asymmetry does not exceed 5% (CIBSE Guide A)

Radiant asymmetry is in close relation to façade configurations, and the shading systems used. (Olsen, *et a*l, 1973) found that no other position of the body in relation to vertical surfaces in an indoor space caused higher thermal discomfort than those nearer to the façade vertical surfaces and especially where large windows are incorporated.

The general design guidelines in hot arid areas (Givoni1976, 1994; Etzion,1994; Sinai 1980) indicates that the main objective of the building envelope is to regulate direct solar radiation.

Special attention must be on designing glazed areas and their shading systems in hot arid areas. The surface of windows experience large temperature fluctuations. The mean radiant temperature close to these surfaces may therefore be higher than the interior space, which may cause occupant discomfort due to radiant asymmetry. The mean radiant temperature can be as much as 25C above air temperature. Therefore, exposure to solar radiation indoors may cause discomfort. This can be intensified by the asymmetry between exposed side of the body and the side in the shade (Goulding, 1993). This effect is in direct relation to glazed areas and internal shading methods.

Windows are generally weak thermally, their inside surface vary markedly with outdoor variations, resulting in asymmetric radiation effects on indoor occupants. The glass absorbs some solar energy and heats up thus becoming a source of heat gain by radiation. If solar absorbing glass is used this effect increases. Reflective glazing is recommended in hot arid climates to intercept a major part of the solar radiation and decrease asymmetric radiation in a room. (Hutcheon, 1965) Internal blinds intercept the solar radiation after it has entered the room. In this case, internal blinds perform as large areas of solar heated panels increasing the radiant asymmetry. Generally, the only means of control is to counteract this radiant asymmetry source by reducing supply air temperature by mechanical cooling systems. The difficulty arises when occupants have control on the shading system, radiant asymmetry values in this case can not be determined and the air-conditioning systems fails to change the room temperature to alleviate these localized effects of thermal discomfort. Therefore shading systems should be placed outside the room space to reduce the radiant temperature and peak solar gains, estimated to be between 5-25 W/m^2 in the perimeter zones of a building. (CIBSE, 2000)

In air-conditioned buildings, the cooled air temperature is normally lower than the mean radiant temperatures of the room. (CIBSE AM:10, 1997) (Fanger et al,

1985) conducted chamber experiments to predict the effect of radiant asymmetry caused by thermal radiation from four different settings, a cool wall, warm wall and a cool ceiling, and a warm ceiling. Results correlated the percentage of dissatisfied subjects as a function of radiant asymmetry (Figure 8). Radiant asymmetry at a warm wall caused less discomfort than a cool wall. A cool ceiling caused less discomfort than a warm ceiling. Accepting that 5% of the subjects may feel discomfort, a radiant asymmetry of 10^0C is allowable at a cool wall. A radiant asymmetry of 23 ^{0}C is allowable at a warm wall. Radiant asymmetry had no significant impact on the operative temperature preferred by subjects, and no differences were reported between men and women.

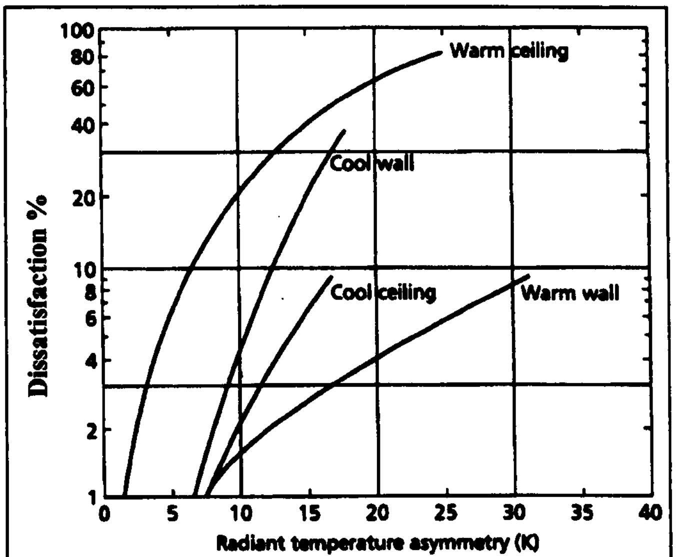


Figure 8: Facades and thermal asymmetry (CIBSE, 1999)

4.3.1.5 Thermal Comfort And Productivity:

Productivity depends on four cardinal aspects: personal, social, organizational and environmental considerations. In many buildings, users reported dissatisfaction with temperature and ventilation, while noise, lighting and smoking featured less strongly. Temperature and ventilation are fundamentally controlled by the building shell and services, while the other factors are affected by changes in the internal layout and workstation arrangements (Clements-Croome, 2000). Though a wide range of literature covers thermal comfort, it is difficult to find a precise relationship between the individual environmental factors and productivity, and trials to determine quantitative relationship between them are highly controversial. However, research carried out indicates a preferred environmental setting by office occupants.

Earlier work (Barkolov, 1963) debated the effect of providing controlled indoor thermal conditions by air conditioning on human activities in hot regions. The study indicated a decrease in typing errors by 24% while work labour turn over decreased by three folds in southern States in the USA and labour productivity increased by 8.5%. Though this study indicates a possible link between air conditioning contributing towards higher productivity. No other study was found that carried out a systematic research to assess the socio-economic effectiveness in qualitative terms for using air conditioning in hot arid regions.

The use of air conditioning to provide thermal comfort over the last 30 years has been linked to increased productivity and economic growth of hot areas such as USA Southern States and Eastern Asia (Fanger, 2001). But researchers in the field of thermal comfort indicated that this increasing dependence on air conditioning in hot climates, not only increases energy consumption but is changing building occupant's expectations, desires and behavioural adaptation measures that traditionally were used to deal with the climate profile.

Earlier work carried out on the effect of the environment on productivity makes deductions about the effect of the environment on productivity based on absenteeism rates, sickness records and accidents (Bedford, 1949). Reviewing literature on the link between thermal comfort and productivity justifies the need for air conditioning in work places in hot arid areas, (Mackworth, 1946) asserted that the overall average number of errors per subject per hour increased at higher temperatures especially above 32 ^{0}C. While (Vernon, 1936) demonstrated relative accident frequencies for British munitions plant workers at different temperatures, and concluded that accidents frequencies were minimized at about 20^{0}C. (Pepler, 1963) examined the variations in productivity in a non-air conditioned mill and concluded that with a decrease in temperature by 5K there was an increase in productivity. Research was carried out in climate chambers, using sample subjects exposed to tightly controlled combinations of thermal parameters. The preference of office occupants to work on the cooler side of the comfort zone was established by work of

(Vernon et al 1926, Bedford 1939) Their work indicated that a 2.5C fall in temperature during summer, or 1.8 C in winter than standard comfort temperatures, increased freshness sensation by one unit. The trend of decreased human performance and its association with increased levels of air temperatures was confirmed by (Rowe, 2001). The research conducted a longitudinal survey on the relation between activity rates and thermal comfort in office occupants in Sydney over a period of two years while controlling the operative temperature between 20 –27 ^{O}C, and concluded that the negative relationship between indoor temperature and activity rates suggests that subjects were deliberately decreasing their activity levels as conditions became warmer.

(Lorsch and Abdou, 1993, and 1994) connote that SBS (Sick Building Syndrome) is likely with warmer room conditions, causing a reduced work output. On the other hand, output improves when high temperatures are reduced by air conditioning. While most people maintain high productivity for a short time under adverse environmental conditions, after which errors and accident rates increases.

4.3.2 Visual comfort

The importance of the luminous environment stems from the assumption that 80% of the information we receive comes from the eyes and is therefore of a visual nature combining the active information seeking process (images focused on the eye retina) and interpretation (brain), which is a highly developed combination of detection and image processing. (Ruck, 1989). From a psychological perspective lighting plays a central role in human perception of spaces. Creation stories speak of the struggle between the forces of light and those of the darkness. Light symbolizes knowledge while darkness symbolises ignorance. Goodness, life and warmth are commonly linked with light while evil; death and cold are linked with darkness.

All daylight strategies depend on luminance from the sun, skies, ground and reflected from other buildings. Availability of natural daylight is determined by latitude of the building site and its surroundings; climatic conditions particularly duration of sunshine. The daylight's performance into a room depends on the light falling on the building envelope, window geometry and the indoor properties of the space.

The interaction between the façade and the occupants in providing the suitable luminous environment is classified into the **physical and the psychological environment**. Both environments interact to produce the final perception of comfort within a specific luminous environment. As in the thermal environments the luminous environment recommendations on which strategy to use for a specific façade design is not clear cut due to the psychological demands on its performance. As the luminous environment impacts energy consumption in buildings, it is the aim of this section to review these physical and psychological aspects in an attempt to understand their effect on façade configuration choices, and to examine the link between the thermal environment and the luminous environment that has to be considered in façade deign and façade refurbishment schemes.

4.3.2.1 The Physical Environment:

The exact relationship between visual performance and illuminance depends upon many factors, which vary with task, individual and environment. The configuration of the façade with its glazing ratios, glazing type and depth of the plan behind the facade all influence the availability of daylight. Typical side lighting windows can effectively daylight the perimeter zone to a depth of 1.5 times the head height of the window (ASHRAE, 2001).

Although this definition indicates a minimum actual area in a floor plan where daylight can be used, it should be argued here that daylight has a psychological effect that exceeds its physical performance in a building. Wells (1965) study demonstrated that beyond 6 m from the window, occupants overestimated the proportion of daylight in the overall interior illumination. This may indicate that having access to daylight regardless of its physical quantity and quality satisfies the need for day lighting, and that its qualitative benefits are more appreciated than its physical performance.

However, the physical performance of daylight is regarded as an opportunity for decreasing dependence on electrical lighting and therefore reduces energy consumption in buildings.

CIBSE(1999) identifies three major areas where lighting must serve a purpose:

-To enable the occupant to work and move about in safety

-To enable tasks to be performed correctly and at an appropriate pace

-To create a pleasing appearance to the indoor place

According to the availability of daylight, the luminous environment uses energy (natural or generated) in three distinctive ways namely **a) daylighting strategies, b) electrical lighting strategies** and daylight assisted (by electrical lighting) **c) hybrid strategies**

a) Daylight Strategy:

IESNA defines light as a visually evaluated radiant energy, or more simply, a form of energy that permits us to see (Stein, 2000). From a physical point of view, visible light is seen as encompassing a narrow range of the total electromagnetic spectrum, which includes radio waves, infra-red light, ultraviolet light and X-ray. Differentiation between the spectrum rays lies in the physical property of their wave length. Therefore admittance of daylight has other thermal implications that are aggravated in hot arid climates.

The profligate use of office buildings to energy aroused concerns even before the energy crisis. (Hardy and O'Sullivan 1976). Argued that the best way to conserve energy and reduce peak energy consumption in buildings is to depend on deep building plans that would reduce the effect of the outdoor environment. They anticipated that using permanent artificial lighting causes minor effects on building energy consumption.

'In buildings designed for daylight, the demand for heating and cooling is determined mainly by changes in the external environment, and therefore produce widely fluctuating demands for heating and cooling. In buildings designed for PSALI (Permanent Supplementary artificial lighting for interiors) Or PAL (Permanent Artificial lighting), the influence of the external environment can be reduced to such an extent that this becomes a minor effect'.

Illumination from windows by daylight is dependant on the combination of **sunlight and skylight**

Sunlight: regardless of the climatic conditions, occupants' reaction to uncontrolled entry of sunlight into office space is similar. Research conducted in temperate and overcast conditions in Europe and especially the UK indicated that sunlight was only appreciated when heating demands were unmet during winter. In buildings where environmental systems were performing well, direct solar radiation was considered a problem and was perceived to be directly related to over heating and thermal discomfort. Ne'eman *et al*, (1976) concluded that from their questionnaire results on 4 office buildings in the UK it was found that the effects of direct sunlight were related to the occupants' seating position and the control they had to ameliorate any adverse effects of the direct entry of sunlight. They concluded that nothing in the data analysis suggested that office workers want sun to be totally excluded from their environments, but more control on its effects on office workers who can not change their location nearer to a façade to avoid direct sunshine were needed.

Direct solar penetration due to clear sky conditions prevailing in hot arid climates and the intensity of solar radiation, has traditionally been treated as unwelcome. Openings are normally shaded from the sunshine by different shading systems such as wooden shutters, fixed concrete louvers or by using specially treated glazing types such as tinted or reflective glazing. It is common practice in hot arid areas to shut wooden shutters during peak mid day hours to obstruct direct solar radiation.

The admission of sunlight is essential to enhance the perception of well being in the workplace, but it has to be controlled to prevent thermal and visual discomfort and interior deterioration of materials.

Skylight: Diffuse daylight compared with direct sunlight is sufficient to meet the lighting requirements of buildings, while beam sunlight is in excess of this requirement. From a visual point of view a sky light whether from a clear or overcast sky is diffuse. Contrasts are then reduced, both within a room and between the interior and exterior. The character is then more restful (Stein,2000) illumination from the skylight should be that there is no contrast between the interior and the view out.

The assessment of daylight factor is predominantly used for moderate climates. Daylight factor is defined as: 'the daylight factor at a given position is the ratio of daylight illuminance at the point to the horizontal illuminance simultaneously experienced outside under a completely unobstructed sky of known brightness distribution'. However the definition indicates that results of this method would only indicate extreme and minor conditions under overcast skies in a hot arid climate. In a predominantly clear sky condition, the daylit area is defined as (CEC,1998) *'the area having a length of 15 feet (4.5m), or the distance on the floor, perpendicular to the glazing, to the nearest 60 inch (1.5m) or higher opaque partition, whichever is less; and a width of the window plus either 2 feet (60cm) on each side, the distance to an opaque partition, or one half the distance to the closest skylight or vertical glazing, whichever is least.'*

It is expressed as:

$$DF= (TA_W\theta/ A\ (1-R_a^2)$$

Where DF is the average daylight factor in (%) for a room

T is the diffuse transmittance of glazing material including effects of dirt.

A_w is the net glazed area of the window in m^2

θ is the angle in degrees subtended by sky which is visible from the centre of the window in degrees

A is the total area of the internal surfaces (ceiling, floor, windows and walls in m^2

R_a is the area-weighted avaerage reflectance of the interior surfaces.

(CIBSE, 1999) recommends that average daylight factor for office work be 5% and not less than 2%

Literature indicates a link between thermal comfort and visual comfort resulting from the utilization of daylight in hot climates.

From observations in Egypt daylight maybe provided through exterior windows or light wells. For overcoming intrusion of direct sunlight some converted office space from (residential buildings) open up windows on light wells. However this approach although denies a pleasant view and may be questionable for a purpose-designed workplace. These concepts raise arguments on if providing daylighting is solely a quantitative problem which will be discussed in the psychological effects of the luminous environment.

A study by (Boyce *et al*, 1995) suggested that if light transmittance within interior spaces was less than around 35% people start to find the view out gloomy. This maybe provided by controlling the VLT values of glazing.

Glare: Glare from windows can be caused both by diffuse skylight and more seriously from direct solar radiation. The reduction of the effect of direct solar radiation requires the use of shading systems to obstruct the intense direct radiation of the sun in hot arid areas. Discomfort glare is the sensation of distraction and annoyance. It is caused by the sharp contrast between the light source and its surrounding areas. Contrary to the temperate cloudy skies, to reduce glare from windows in hot arid areas window sizes were classically made smaller. If larger window areas were used then these would be covered by the wooden lattice (Mashrabiya). *A discussion of this shading system and its suitability is in the section Building and their Shading systems in (chapter two).* Large window areas would allow the view of the highly bright sky light in contrast to conditions in the room thus requiring a higher eye adjustment levels. (Fathy, 1986). But reducing window sizes does not necessarily solve the glare problem.

The assessment of glare depends on several variables including window size, the quality of view, the degree of specular reflections from interior surfaces and the wall area surrounding the window. CIBSE LG3 (1996) indicates glare as a main determinant of the use of window and shading systems in current workplace where visual screens are used, curtains are drawn to shut the windows in cases of glare. Reflections are always present in glass-fronted display screens. It is the elimination of distracting reflections that is important. Disturbing reflections at the workstation can often be eliminated by suitable re-orientation of the screen or workplace rather than by relighting the entire space. Windows and sunlight translucent window screens are likely to cause more problems with glare and screen reflections than electric lighting.

However the negative effects of glare on visual comfort during work performance may conflict with the cheerful and positive psychological effects of sunlight which to a degree can offset glare discomfort.

Boubekri and Boyer (1992) studied the effect of window size and sunlight presence on the perception of glare in indoor spaces in Texas USA, their investigation involved 40 subjects and varied the window to wall ration between 10%-60% using low transmittance glazing on all apertures of light transmission of (0.46) (Figure 9). There study concluded that the perception of glare was in relation to the occupants seating position in the room and was more significant in the position facing the window that the side lit position. The results also indicated that the relationship between the calculated glare and window size. Perceived glare index increased as the window increased from 10% to 40%, then decreased as the Window to Wall ratio increased to 60% of the wall. This was attributed to the fact that glare is high for medium window sizes due to the high contrast between the glaring source and the adjacent windows. For small window sizes the glaring source is small and the perceived sensation of glare is disturbing. For large window sizes although the glaring source is large, the contrast between the source and the surrounding is small, raising the adaptation level of the eye thus reducing the glare sensation and its degree of discomfort. However, the study also took into the consideration that these findings may be inherent to the occupants' bias and gratitude to have a window and a view, as they were not provided with windows in their original workplaces, which on its own may relate increased tolerance to glare to other psychological aspects concerning the view out. The decrease of perceived glare with larger window areas is in agreement of findings by Chauvel and Dogniaux (1982).

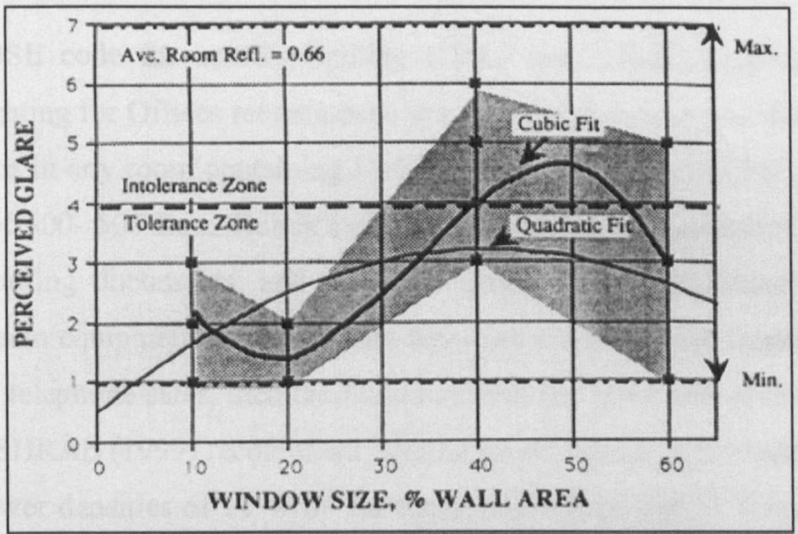


Figure 9: Relationship between glare and window area (Boubekri and Boyer (1992))

b) Electric Lighting Strategy:

The use of electric light is a necessity for illuminating interiors after daylight hours or in areas deprived completely of daylighting due to depth of plans or underground situations. Use of electric lighting in areas adjacent to facades where daylight is available is linked with wasted energy. Although studies indicated preference of occupants' to work by daylight, complete dependence on electrical light during daylight hours is not excluded.

The use of drapes or blinds to completely exclude daylight and view and depend on electrical lighting stems from the need to reduce glare on desk level or on visual display units or for privacy reasons. *'where glare is a problem, users may keep the blinds down and lights on leading to excessive and unnecessary energy consumption by electric lighting*' (CIBSE, 1996:19) The lighting conditions provided by codes are based on providing best practice conditions, however these levels of lighting are designed for situations where no daylight is available and night time conditions are assumed the presence of daylight may impose 25 times greater levels in an area close to a window, even without the presence of direct sunlight . (BRE Digest, 1983). Due to the expanding dependence on personal computers in the work place environment, lighting requirements have been redefined.

CIBSE code for interior lighting (1996) and CIBSE Lighting guide LG7 (1993): Lighting for Offices recommends that the design maintained illuminance over the task area in any room containing Display System Equipment (DSE) should be in the range of 300- 500 Lux. This is a compromise between illuminance necessary for reading working documents, and the most comfortable illuminance for operating display system equipment (DSA). Where tasks are mainly screen based, such as data retrieval or telephone sales, then the illuminance at the lower end of the range should be used. ASHRAE (1999) recommend lighting levels should be provided by no more lighting power densities of 14 W/m^2 for open plan offices and 17 W/m^2 for enclosed offices.

Literature has systematically claimed energy savings through substitution of electric lighting by daylighting. Baker (1999) estimated that in a typical shallow plan office building, with a plan depth not greater than 15m and occupied for normal working hours, could obtain 70% of its working illumination by daylight.
Where daylighting is unavailable there needs to be a stringent application of the code recommendations as the variations of brightness from electrical lighting over a small distance can be greater than the gradual variations associated with daylight and gradual fall off in illuminance is a smooth curve as a function of the distance from a window.

Hunt (1979) indicated that the probability of switching on artificial lighting on entering a space correlates closely with daylight availability at the time but switching off rarely occurs until the last occupant has left. The leading research invited further research in various automated and localized switching off of electric lighting strategies.

c) Hybrid Strategies:

The use of electric lighting as indicated in the previous section is essential in non-residential buildings, to create a pleasant and productive working environment. Although lighting is a major contributor to electricity consumption in buildings, the use of automatic controls to switch it off and make use of daylight were proposed in several studies to complement other energy saving measures whether in new built or refurbished buildings (BRE digest, April 1983)

Admitting daylight without sufficient controls affects its real contribution to energy efficiency. BRE (Digest 272, 1983) suggests that although in non-domestic buildings, electric lighting is essential for a pleasant and productive environment, waste in energy occurs mainly in two ways: the use of full artificial lighting when daylight is sufficient to meet part or all of the lighting requirements, and lighting being maintained when occupants are absent. The digest suggested alternatives to traditional switching on/off controls and guidance on suitable controls classified in accordance to a ranked assessment of possible control strategies in terms of economic returns.

Lighting controls are basically classified into five categories:

1. Manual
2. Timed switched off with manual reset
3. Photoelectric switching on/off
4. Photoelectric dimming
5. Occupancy sensors.

Top up electric lighting is required when the following conditions occur:
The condition of the sky are variable thus affecting the interior illumination and creating difficulty in maintaining constant luminance for task performance.

-Although side lighting from windows enhances dimensional modelling and colour rendering of the interior but its varying spectral distribution during the course of the day affects the quality of daylight itself (BS 8206-2:1992)

However estimation of the use of electric lighting based on overcast sky conditions may underrate the possibility of electricity savings by utilizing daylight. California Energy Commission (1998) where predominant clear sky exists suggests the utilization of the Effective Aperture method. '*The Effective Aperture (EA) for windows equates to the visible light transmittance (VLT) times the window wall ratio. The window wall ratio is determined from the Exterior Wall Area of the room. Windows with an EA greater or equal to 0.1 indicate sufficient daylight availability to* *require separate control for the daylit area.* This method is used in this thesis to test he availability of daylight in all scenarios.'

The fast development of technologies to redirect daylight into spaces have been excluded from this review as there development is still under scrutiny due to unresolved technical issues and problems namely 'Task 21, report'

Most daylight systems prevent an unobstructed view to the outside and consequently a distinction is made between the view window and the daylight window.

When hit by direct sunlight, many of these systems reach extremely high luminance causing severe glare problems, and therefore must be used above eye height of a standing person.

Fixed systems designed for diffuse daylight may serve as a shading device but few and expensive systems will improve daylight penetration

These systems can not actually increase the amount of daylight entering through the window opening.

4.3.2.2 Psychological aspects:

Literature on the psychological aspects of lighting into three classifications namely; perception of the outdoor environment perception of indoor spaces;, influence of light on arousal, mood and cognition and the impact of light on chronobiology.

Perception of indoor space may be explained as the perceived modelling of contents, brightness and spaciousness. These perceptions have been linked to daylight entering through façade configurations and interior colours used on walls and partitions. Inui and Miyata (1973) through studies on scaled models where sky illuminance, window size and interior illumination were changed concluded that spaciousness was not related to the method of illumination nor to the type of furniture. Satisfaction was most correlated to window size with a larger window giving greater satisfaction and greater effect on perceived spaciousness. Increases sky luminance and room volume and windows at eye level were also correlated to the feeling of spaciousness. Collingro and Roessler (1972) (cited from Aoul, 1991) administered a questionnaire to investigate variable window size and illumination level upon feelings of enclosure. Their results indicated that spaces with no windows or with small windows created extensive feelings of enclosure that where not reported with large windows. Although an increase in artificial illumination reduced some of these feelings, but the authors believed that it is not a compensation for a windowless environment or one with a very small window.

The visual light transmittance from glazing material and its effect on perception of the indoor space was studied by (Cooper et al, 1973 and Hube, 1995). Cooper *at al* (1973) studied the perceptions of 900 office workers in high rise office buildings. Glass transmittance in the study was ranged from 15%-85%. The questionnaire assessed reactions towards the availability of a view, the content of the view. The results suggested that tinted glazing had no effect on the visual environment and this was in part attributed to adaptation of the visual system to the available interior conditions. Hube (1995) used two south facing experimental rooms in the School of Architecture in Lund to assess the subjective reactions to daylighting in a room, comparing the effect of using clear and low-emittance coatings on users perception of the indoor space. The research sample consisted of 51 females and 44 males, averaging in age between 18 and 72 years. Windows' daylight transmittance was 72.6% for a triple clear glazing system and 57.3% for a four pane with two reflective low e layers. Results indicated that there was a tendency to assume a darker outdoor climate but also less perceived glare was reported with the super insulated window than the clear three pane glazing. The study also reported perception of a dark interior and drab colours inside and outside resulted from the questionnaire analysis.

Few studies have attempted to study the minimum acceptable glazing transmittance in clear sky conditions. A study by (Boyce *et al*, 1995) suggested that maximum acceptance (85% of responses) were associated with visual light transmittance of glazing systems and sky conditions. The study concluded that the minimum acceptable glazing transmittance lies in the range of 25% to 38%. With the minimum acceptable transmittance highest for an overcast sky, while lowest for clear sky conditions. However, these results should only be regarded as indicators, the short time related to respondents using the scale models may influence their subjective responses.

Perception of the outdoor environment: Windows play a major role in providing occupants with visual amenity by connecting people to the outdoor environment. It is impossible to quantify the value of a view in physical terms. But in real estate a view has a monetary value. Offices and apartments with a good view command substantially more rent or purchase prices. If the direction of the view is undesirable in terms of solar heat or glare, and even if architectural details will cost more to offset these solar loads, it is often the case that the value of the view exceeds those costs.

Four general psychological benefits related to a window are summarized as:

- Access to environmental information
- Access to the world outside
- Restoration and recovery
- Access to sensory change

(BS 8206-2:1992) recommends that unless an activity requires the exclusion of daylight, view out-of-doors should be provided irrespective of its quality. Several studies linked the access to a view as an important buffer to work related stress (Markus, 1967; and Kaplan, 1995)

The quality of a view is defined by the presence of three layers:

- Upper (distant), being the sky and its boundary with natural or man made scene
- Middle, being the natural or man made objects themselves
- Lower (Close), being the ground scape forming the foreground of the view

Views including all three layers are the most satisfactory. However within the urban context the provision of this type of view becomes difficult. (BS 8206-2:1992) recommends that when only sky and buildings are available, it is desirable to provide a dynamic view to the outdoors, while a static view is considered better than none.

The view out is recommend by BSI in relation to room depth, however it is stated that these recommendations have to be re-evaluated for each building design for its climatic and environmental context to ensure a good daylight quality.

Table 5: Minimum glazed areas for view when windows are restricted to one wall

Max. Depth of room from outside wall	% of window to wall ratio as seen from inside
< 8m.	20%
8-11m.	25%
11-14m.	30%
>14	35%

However, the importance of the view seems to be under rated in some research results. Wotton and Barkow (1983) carried interviews with 235 office workers in six office buildings with Window to wall ration glazing varying between 11% to 68%. The results stated for the case study buildings that for the majority of staff it is important to visually link to the outside world. Further, the respondents preferred to have the windows located near to their workstations. But as the respondents were asked to choose between fourteen factors and rate them in scale of their importance to make their workplace pleasant and comfortable the good view came last. Care should be taken when looking at results of these studies as semantics of the questionnaire might have not been clear to the occupants. Although the occupants expressed a strong desire to be near to a window, their implying response that a good view rated least maybe to indicate that they would need a view out of the window with whatever kind and quality of a scene and that the good scene (natural scene) is not important. The other aspect in interpreting these results to such studies is that these occupants already have windows and take their presence for granted and therefore may be expressing their dissatisfaction with other environmental aspects

Heerwagen and Orians (1986) compared the use of visual material between window and windowless offices. Their research listed in details the contents of wall décor used in 75 offices. The research concluded occupants of windowless environments used twice as much visual material compared to those occupants with access to a view. The contents of these surrogate windows were more of landscapes and less of cityscapes. But this 'compensation hypothesis' was contested by Biner *et* *al* (1993). The results of their series of studies to determine how and why workers would compensate for the lack of a view concluded that indeed workers whether near or away from windows used plants and pictures as to confirm the personalization of their spaces. This again emphasizes the importance of the window as both a physical and psychological determinant of the workplace and the ability or the possibility to compensate for this need has not yet been proven.

Daryanani (1984), states that the most important benefit of the application of daylighting in commercial buildings is not energy conservation, but increased occupants' satisfaction... *'If energy conservation was the only criterion for success of a commercial building, a windowless underground building would be the ultimate energy conscious design.'*

However although clear glazing is considered best for an unchanged view to the outside, for energy performance reasons, several glazing materials are used to decrease the direct solar ingress into the workplace. These maybe divided into **treated glazing or solar shading systems.**

Unknown to the viewer tinted glazing can affect colour perception. External colours appear distorted, especially when the view outside is seen simultaneously through different types of glass and perception changes of internal colours.

Although from a thermal point of view all fenestration in positions where sunlight may cause discomfort (over heating near window panels or glare) should be provided by shading systems. In hot arid areas it is common practice to shade openings with balconies, overhanging rooks, or fixed louvers. Shading devices may interrupt the view out and restrict natural ventilation.

Aoul (1991) studied the effect of using sunbreakers on the minimum acceptable window size for a view. A view preferences between two groups of students, one living in temperate climate (British) and recently arrived from Hot arid climates (Algerian students) were questioned used a scaled model on which various combinations of a view were used. The results concluded that the shading devices were generally perceived as an undesirable visual intrusion, resulting in a psychological sense or irritation, dissatisfaction. The hypothesis to increase the window size to compensate for the loss of the view was not justified, and respondents preferred a smaller window with different shading systems to minimize their visual intrusion effect.

Although it may be a conclusion that a clear glazing large window on a natural scene is the optimum for control of lighting and visual effects using tinted or reflective glazing appears to be less intrusive and with less psychological effects than sunbreakers.

Mood and cognition reviewing an extensive literature Russell and Snodgrass (1987) deducted that there is a relation between mood and human cognition. Belcher and Klunczny (1987) indicating that there is an association between light and the decision process resulting from autonomic arousal and mood. Hughes (1983) stated that the information the brain receives from the illuminated environment is an essential element in shaping our moods, reactions and psychological well being.

While other studies related the availability of daylight to changes in muscular activity, rate of breathing, pulse rate and blood pressure (Plank and Schick, 1974).

Effect of daylight on chronobiology:

The effect of sunlight as a component of daylight is linked to several chronobiological disorders. Sunlight is linked with the suppression of the melatonin secretions that are related to inducing restful sleep, and regulating human biorhythms controlling daily changes of Physiological processes in the human body stimulated by daytime light and night time darkness. It is generally believed from the bulk of literature on SAD (Seasonal affective disorders) that it is linked to further from the equator latitudes and duration of daylight. SAD is a form of depression linked to increased duration of sleep, increased appetite, weight gain, and carbohydrate craving (Tam *et al*, 1997). However reports on its presence in lower altitudes in South Africa and India (as hot climates) (Sazabo and Bianche 1995) pointed out that SAD is linked not only to the duration of daylight but to exposure to sunlight, which may then justify the application of the British Standard recommendations on sunlight entering indoor spaces in other climates (discussed earlier in daylight strategies).

However the over exposure to the direct sunlight is problematic. In hot arid areas it is easily observed that there exists a common consensus among people to avoid exposure to direct sunlight. Direct sunlight mainly consists of the visible radiation range, as well infrared radiations and ultra violet radiation. Effects of infra red radiations is related to heating of skin surface, inversion of bodily functions such as circulation, respiration and the nervous system. Ultra violet radiation also has an external effect on skin pigmentation and on internal body systems via the skin. Irradiation of the skin by short or middle wave ultraviolet radiation causes a secondary pigmentation of the skin (tanning) as a consequence of the acceleration of the formation of melanin. Continued exposure of the skin can lead to changes in the epidermis known as the preceding stage of skin cancer (Ruck, 1989). However, this adverse effect of exposure to strong sunlight can be avoided by appropriate shading.

But due to the hygienic sterilizing effects and for psychological reasons, British standards suggests direct sunlight has to be admitted in the workplace at least 25% of probable sunshine hours and 5% in winter (BS 8206-2:1992). Boubikri *et al* (1991) conducted chamber experiments on the effect of sunlight penetration on mood of office workers. The research concluded that moderate amounts of sunlight penetration between 15-25% seem to be most optimal for tasks requiring relaxation appropriate for tasks needing high concentration such as office work. Very large sunlight penetration causes opposite feelings that are low pressure and high arousal causing the occupant to desire to avoid such places.

4.3.2.3 Linking thermal and visual environments:

Because of the nature of visible light as a form of energy, there is an inseparable association with its impact on thermal discomfort and increasing building cooling loads (IEA task 21). This situation is aggravated in hot arid areas in predominantly clear sky conditions. It is noted that daylight in different climates in wanted to a threshold level above which or under which it is considered as a detriment for task performance.

Day light factors are an indicator of the availability of daylight in the interior space however its excess or minimization is considered an annoyance. Roche *et al* (2000) surveyed 16 office buildings around the UK of recently refurbished electrical lighting systems. In all buildings, 20 respondents were chosen for a questionnaire. Their results indicated that higher levels of day light factor (above 5%) were indicated by occupants as unsatisfactory and were not preferred to lower Daylight factors. The authors attributed this finding due to excessive levels of daylight being associated with stronger physiological effects such as glare and overheating. Also lower levels of daylight are easily supplemented by electric lighting. While higher daylight factors are associated with glare leading to pulling down of curtains and electric lighting being switched on. However the results indicated that the main preference of occupants was to work by daylighting, their second choice was working under daylight supplemented by electric lighting and only 4% of the sample preferred working by electric lighting alone.

According to Heerwagen *et al* (1985), users' expectations in terms of illuminance may be linked to thermal conditions and on climatic conditions. The authors have noted that for example in summer it was observed that office occupants who experience high temperatures deliberately work at daylight levels less than those recommended (for instance with blinds closed) without turning on lights, as if dimness is symbolic of coolness. This assumed link between thermal and visual conditions been examined by Yamazaki (1998). The research investigated effects of air temperature, light and sound on perceived work environment. Sensations of 16 subjects were recorded in ambient temperatures of 19 ^{0}C to 29^{0}C, and varying desktop luminance between 75 lux to 1500 lux. Results pointed out that when illumination was low the sensitivity of reaction to temperature is low, while with increasing luminance the sensitivity to temperature increased. This relates to closing windows and shutting off views in hot arid areas and the dim light behind wooden shutters of office buildings in Cairo observed during field visits during peak hours in summer. However it is argued that the psychological effects of these strategies may have an effect on occupants' satisfaction.

4.3.2.4 Occupant's control:

Studying occupants' control stems from a need to identify the extent upon which architecture is allowed to deal with human demands and interact with both outdoor and indoor environments. Understanding aspects and demands of human control on their environments improves building performance and has an impact on the extent of technology adoption within buildings, and further dictates types of energy saving measures that maybe pursued.

Human habitation patterns changed from adopting nomadic living patterns to construction of permanent dwellings. This form of change has been attributed to man's need to control his environment rather than self adapt to it (Madhavi & Kumar, 1996). Humans adopted nomadic lives within their dwellings, such as the middle-east courtyard houses, where occupants shifted their accommodation within the dwellings in accordance to seasons. In summer North oriented rooms were used for daily living, while in winter South oriented rooms were inhibited. However, this migratory living pattern did not prove satisfactory. As opposed to literature claiming that traditional architecture offered environments suitable for modern users, (Hanna, 1997) contested the theory by studying occupants' satisfaction with their thermal environment and their ability to control it. The study considered 30 traditional courthouses and modern European adapted houses in Iraq. The questionnaire results indicated a lack of acceptance of the thermal comfort in traditional housing. Occupants pointed out poor control on the indoor thermal environment, as they had to move into the uncontrolled environment of court whenever they moved from one room to another. The choice and availability of control options were favoured in new housing types without the court.

The dominance of mechanical building services early in the 20th century modern movement and the appearance of the completely sealed office building, led psychologists and researchers to embrace the view that lack of occupants' control over their environment led to feelings of unhappiness, decreased task performance and decreased well being (Averill, 1973, Burger, 1989). In an attempt to increase building automation to minimize energy consumption, intelligent buildings were introduced in early seventies as a concept and in practice due to the phenomenal advances in computer technology, as well as advances in building materials. It was then believed that a single computer could efficiently manage and integrate the building services and systems. This was believed to attain better-controlled, extensive system monitoring and optimum services efficiency. The intelligent building was defined as 'the one that creates an environment that maximizes the efficiency of the occupants of the building, while at the same time allowing effective management of resources with minimum life-time costing. In this context, intelligent buildings claimed the provision of more centralized control while further reducing the need for human exertion or the need to account for occupants' control (Robathan P., 1989).

By late 80's, studies in different countries that adopted the universal modern office building with its sealed envelope, relaying on the so called intelligent controls, was giving indicators on occupiers discomfort within these buildings. Building occupants were undedicated to the automated systems and spent time trying to find creative ways to circumvent and sabotage these systems. Thus the attempt to produce intelligent buildings simply by adding computers and communication networks to a building usually failed to deliver the anticipated advances (Boyd,1993). Modern buildings were moving in the direction of more assertion of control on the natural environment. Mawson (1994) asserted that intelligent buildings in many parts of the world were designed with a technology push to demonstrate a clever 'gadget', and did no seem to integrate those sophisticated systems to meet any particular user objective. Intelligent buildings were designed as monuments to the engineers and architects, rather than providing, meaningful, valuable, manageable places to support people in their work. This emphasized occupants' need for local and individual control over environment and the desire for uncomplicated technologies and more building integration with natural systems.

Complex controls and energy saving features can sometimes be too complicated for their management and for occupants to use, leading to more wasteful energy than simpler technologies. Bordass et al, (1995) surveyed the energy utilization and controls provided for 16 different office buildings in the UK with different operational systems ranging between naturally ventilated, fully air-conditioned and mixed modes. There study indicated that the provision of controls does not indicate users comfort or ensure energy efficiency. Although the prestige air conditioned buildings was supplied by an impressive list of building controls it consumed 2.5 times higher energy than another air-conditioned building that had less energy saving features but a responsive and an aware building energy management. The study concluded that perceived control depended not only on the presence, design and placement of control devices, but also on the overall effectiveness, ease of operation and responsiveness of these controls to ameliorate the affecting condition. The study also indicated that naturally ventilated buildings if poorly designed offered the worse case in terms of energy conservation.

Calls emerged for allowing occupants' more control over the indoor environment and allowing them to adapt themselves to what is subjectively considered as a comfortable indoor environment. This trend reached its zenith in the early 90's. A Japanese construction company intended to offer the very latest in workplace comfort by providing employees with the latest in control strategies. 'Employees will carry an identification card that holds personal data on their favourite room temperature and level of brightness. These cards will transmit the data on an electric wave to sensors installed in the walls. The sensors will detect who is nearby at one given time, and automatically set the appropriate level of lighting, heating or air conditioning' (Waller, 1993 in (Mahdavi and Kumar, 1996))

These adaptive opportunities are argued in literature as an option to reduce building energy consumption for building services, while increasing occupants' satisfaction (De dear and Brager,2001). Thus, control given to occupants of their indoor environment has evolved from a complete exclusion of the natural environment, in the early 20th century, towards increasing man's control to admit calculated elements of the natural environment by late 20th century. Thus, decreasing dependence on human self-adaptation towards assertive but interactive controls on the natural environments. These requirements are based on supplying occupants with more control on the building services and mechanical systems while integrating the building design with the bioclimatic forces of its particular location. Examples of these are numerous around the world such as Sir Norman Foster's Commerze bank head quarters in Germany and Ken Yaeng's Minara Miseniara in Malaysia.

Occupants' control has been classified as **available control, exercised control and perceived control** (Pacuik, 1989) Available control is seen as an adaptive opportunity, while exercised control is a form of behavioural adjustment, and perceived control refers to occupants' psychological expectations (Brager and de Dear, 1998). Perceived control is a complicated concept, based on decisional control and cognitive control (Avrill, 1973). (Barnes, 1981) argued that perceived control is the perception that one's choices (decisions) determines the outcomes, it is based on previous experiences (cognitive) with 'perceived freedom' to choose between alternatives to alter the physical environment. These pervious experiences are desirable to enhance choices made by occupants to modify their indoor environments. In Avrill's words experience gained from modifying indoor conditions using *decisional control* enhances *cognitive experiences*.

Although in the office environments several control strategies may be present, namely controlling the thermal and visual environments, the occupants' interact with the façade as a primary source of control on temperature, ventilation and daylight.

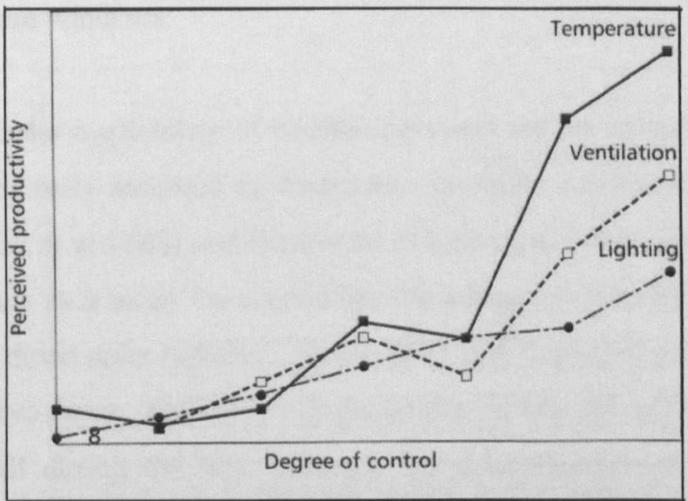


Figure 10: Relationship between perceived control and productivity (Raw et al, 1990).

Figure 10,indicates the relationship between perceived productivity and perceived control. Raw *et al* (1990) indicated that office occupants ranked their preferences over control by control over temperature, ventilation then lighting. . These findings were acknowledged by Stevens (1999) studied occupant interaction with automated building systems by surveying fifteen office buildings in the UK, with 453 occupants with different control strategies, ranging between selective, exclusive and hybrid façade systems. His study concluded that control over lighting was held to have significantly less importance than control over façade elements; windows and blinds. However, if automation of the façade involved loss of occupant control, increased dissatisfaction was observed. From these observations, it is concluded that occupants would depend on electrical sources of lighting if required but would not sacrifice a view out of the window, or the ability to open the window to quickly ameliorate odour or indoor temperature conditions.

As executives are assigned individual workplaces where indoor available controls are maximized, the provision of control has also been linked to a perceived demarcation of status Aronoff and Kaplan (1995). This trend towards hierarchal segregation of available controls is driven further when workplaces near windows are reserved for higher ranks and corner window location to the highest ranks (Sunderstrom, 1986), leading to a perceived lack of control to those occupants' situated away from windows.

However the availability of control does not ensure its proper or continues utilization as originally assumed by designers. Available and exercised control were studied by (Inoue, et al 1988) and (Foster and Oreszczyn, 2001). Their study focused on utilizing blinds as a mean for controlling the indoor environment as a reaction to control glare or direct solar radiation. (Inoue et al, 1988) studied four high-rise office buildings in Tokyo-Japan. The study concluded that an average of 60% of blinds were not moved at all during the day, although the questionnaire on office occupants revealed their preference to a space near a window. (Foster and Oreszczyn, 2001) studied three buildings in the UK by video surveillance in both summer and winter conditions. Their study concluded that opposed to current theory, occupants' use of blinds is predominantly not affected by daylight availability, orientation, or sunshine. The study argued that assuming 100% of daylight was available from windows, due to occlusion of facades the area of which daylight penetrated was only 68%. However the results also indicated that the unexpected use of blinds on North facades maybe due to the need for privacy from adjacent building users.

However, providing automated shadings to improve the buildings façade thermal performance was met with hostility from building occupants. This is attributed to its interference with the view out of the building (Bordass and Leaman, 1995). Occupants surveys of eleven buildings by BRE indicated occupants willingness to endure some higher temperatures on occasions than have blinds automatically closed, leading to reduced daylight availability and intrusion on their choice and control of the indoor environment (Bordass *et al*, 1994). Although the previous studies advocated manual control as the preferred control procedure for indoor environments, Vine *et al*, (1998) held a pilot study on 14 federal office workers response to automated façade systems in test chambers. Their study allowed occupants to manually control the Venetian blinds by a remote control. The study advised that on utilization of remote controls, these systems has to provide fast feedback to office workers, as delays will create an erroneous impression that the system is not operating, this may be maintained by a simple green light on the controller. Furthermore, adding more control options to the remote controller increased workers perceived control.

Paciuk (1989) investigated control in relation to satisfaction with thermal environments and thermal comfort in ten office buildings. (Veitch and Gillford, 1996) studied perceived control over lighting conditions in an office environment test chamber, by allowing occupants to change their illumination levels. Both studies concluded that availability of control by providing adjustable environmental controls enhanced the perceived control of occupants contributing to satisfaction. However if the need arises to exercise control 'behavioural adjustments', this indicated a decrease in satisfaction with indoor conditions. Therefore the availability of control for occupants to demonstrate '*decisional and cognitive control*' contributes to satisfaction but behavioural control decreases satisfaction.

However, Occupants do not exercise control unless major indoor stresses occur. Warren and Parkins (1984) studies indicated that users tend to control windows in two distinct modes: either as a means for odour dilution, or to reduce overheating. Most occupants appear to open windows only when room conditions reach temperature thresholds. To control a perceived air quality occupants tend to take action on entry to the room, but during occupancy they are less aware of deteriorating air quality. It has been observed that occupants used small openings to dilute odour and large ones to reduce overheating. If there is sufficient natural cooling provided by background ventilators, occupants generally do not feel the need to open windows. The overall result is that windows are opened less than expected. Practical experience indicates that there is a trigger of internal temperatures at which building users perceive the need to overtake the indoor temperature controls. This occurs when internal temperatures exceed 26^0C. However, the study acknowledged the need to provide controls over windows, even if indoor conditions proved satisfactory.

Yet providing occupants with control to select their desired exposure to the climate without a degree of automation, supervision, or training may prove detrimental to building services performances, leading to wasted energy resources and also to occupants' discomfort (Stein and Reynolds, 2000). Lack of information on the proper utilization of control as a 'behavioural adjustment' leads to increasing stress levels, as subjects' fears that a poor choice could lead to failure to achieve the desired outcome or lead to embarrassment (Burger, 1989). The second aspect of uneducated users control is the effect their decisions affects energy consumption. In hot arid climates where outdoor temperatures exceed comfort limits opening windows during peak summer time temperatures results in a swamping heat effect by the incursion of hot external air into the cooler indoors. This situation is aggravated in mechanically air-conditioned buildings where energy used to cool the air is lost.

However providing building control to occupants is not the sole means to improve perceived comfort as this assumption ignores other building defects that might affect the perception of indoor comfort. These defects range between extremely inappropriate structures, poorly designed ventilation systems, incomplete mechanical system execution, poor maintenance, post installation changes or lack of systems integration with building fabric, changing interior layouts that obstruct usability of these controls, and a lack of responsive building management system.

4.4 Summary

This chapter started by defining the façade and its expected role. It is argued that a holistic approach underpins a successful façade refubishment scheme. Due to the demanding climatic and environmental context of Cairo, This chapter focuses on the role of the facade as a climate-environment moderator and a psychological manipulator. It is argues that occupants satisfaction with their indoor environment is linked to the facade and its performance.

- Occupants environnemental satisfaction is discussed in relation to thermal and visual comfort, the possibility of natural ventilation and the degree to which occupant's can control the facade's role as a climate-environment moderator.

- These environmental psychology determinants underpin the conclusions on a balanced facade technology, in terms of balancing requirements for reducing building energy consumption with the need to sustain and improve occupants' comfort by using air conditioning.

- The literature reviewed research aiming at improving thermal comfort in the workplace, and chances to change occupants' expectation to reduce reliance on energy utilized in air-conditioning systems. The extensive literature review indicated that there was no grounded evidence that thermal comfort levels in hot arid areas were different than any other area. This further emphasized the need for air-conditioning to achieve thermal comfort levels and retain occupants' performance at work.

- Two theories have been reviewed the constancy theory and the adaptive theory. The constancy theory depends on mechanical systems to attain thermal comfort while reducing dependence on human thermoregulatory mechanisms. The adaptive theory in contrast depends on increasing human interaction with the space and relies on human thermoregulatory. The later theory offers opportunities to allow more for occupants' control on their indoor thermal environments. Earlier research in the adaptive theory resulted in cautious recommendations provided for indoor conditions that were slightly higher than air-conditioned spaces. However, recent research based on the earlier studies recommended significantly higher dry bulb temperatures, and operative temperatures than those adapted for air-conditioned buildings. Research on occupants' attitudes within the workplace indicated occupants' unwillingness to change their expectations or habits to conserve energy. From the literature reviewed, the way forward seems to be by improving efficiencies of mechanical systems providing thermal comfort in the workplace.

- Counteracting thermal boredom by allowing occupants to experience different thermal sensations for sensory simulations. This may be designed for designated functions, such as in printing rooms, cafeterias or washrooms but not in the workplace where occupants need to concentrate on their work and not on improving their environmental conditions, whether by physiological or psychological modifications. In workplaces bursts of air may be used to break the thermal monotony and to offset growing discomfort in peak times (de dear and Brager, 2002).

- The literature review indicated that occupants' might experience temperature fluctuations of up to 25^{0}C dry bulb temperature (as opposed to 23^{0}C dry bulb temperatures maintained during air conditioning operation) but for a limited duration of the peak outdoor temperatures, which is applicable in-between summer and winter seasons when outdoor climatic conditions are mild in hot arid regions. In summer month it is difficult to maintain indoor temperatures to thermally acceptable limits as outdoor dry bulb temperatures during working hours exceeds 32^{0}C. Humidity levels have a milder impact on thermal comfort for cooler temperatures, but humidity levels will need to be reduced indoor temperatures exceeds those recommended for comfort.

- The literature indicates a limit on occupants' expectations of the indoor environment to follow track of outdoor temperatures after which they require a disassociation between the two environments and for mechanical environmental controls to take over. Implications of adopting higher indoor temperatures on productivity have not been thoroughly investigated. While conserving energy used in building environmental systems is a paramount goal, efficiency and productivity of the work place occupants' is overriding of any other concern. From literature reviewed it is concluded that outdoor conditions can be used to provide thermal comfort only if conditions indoors are maintained to similar levels of those air-conditioned buildings operative temperatures and humidity levels.

- In Conclusion, for an optimum work performance a well-controlled indoor environment fluctuates between comfort and slightly cool discomfort. It remains to architects to optimise the thermal performance of the building envelope and building services engineers to provide energy efficient solutions to reduce buildings energy consumption. While hybrid systems integrating air-conditioning systems and natural ventilation may be used pending on occupants' acceptance in between seasons.

- According to the availability of daylight, the luminous environment uses energy (natural or generated) in three distinctive ways namely daylighting alone strategies, electrical lighting alone strategies and daylight assisted (by electrical lighting) hybrid strategies. The luminous environment in turn affects the psychological perception in three ways perception of indoor spaces; and influence of light on arousal, mood and cognition and the availability of a view

- From the literature review from the occupants' point of view daylighting seems to have a qualitative psychological effect that overwhelms its quantitative values for task performance.

- Whether luminance is provided through lighting or daylighting the attainment of visual comfort relies on adequate illuminance to perform tasks, limitation of glare, and a suitably bright interior while providing an acceptable trade off in window design between thermal and visual aspects.

- The façade plays a primary role in providing daylight, however in what would be considered an affective daylight zone behind a façade the utilization of electrical lighting is not ruled off in several cases to top up the performance of daylighting

- As the glazed area in a building's façade creates the major influence on daylight while having an affect on overall thermal comfort, it is prudent to examine the window to wall area to provide suitable thermal comfort with minimal compromise to daylight.

- In Hot arid areas it is commonly perceived that large window to wall areas create an uncomfortable and excessive levels of daylight inside rooms, Boubekri and Boyer (1992) study indicated that a 40% of window to wall ratio was perceived by occupants' to reduce glare. This assumption will be used later in chapter 5 to construct the Base Case.

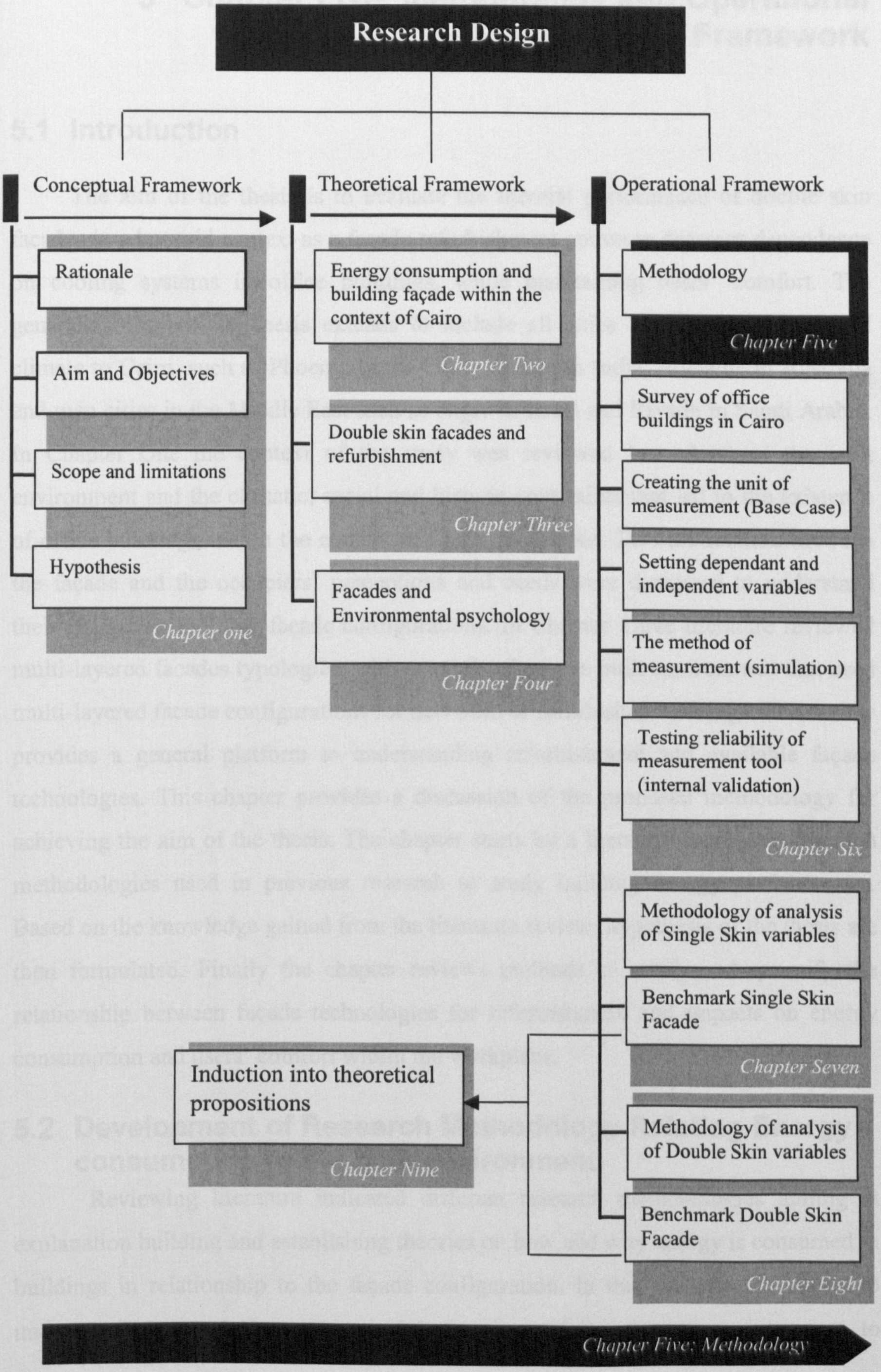
- From a users' control perspective studying the previous literature indicates that although availability of controls does not ensure satisfaction with indoor environments or their proper utilization by occupants, a perceived degree of occupants control has to be achieved. The availability to open a window even in an urban area is seen as an advantage. Although Individuals will tend to use controls only under extreme environmental discomfort, these controls have to be available, easily used and seen within the space.

- An educational process for users must accompany providing controls. The challenge is to involve but not to enslave users in the management of their environment. The educational process increases occupants cognitive experiences and helps them perceive empowerment to alter their controls, without fear to upset others or personal embarrassment.

- Glazed areas maybe differentiated by size and location to provide different functions of ventilation, daylight or views out.

Chapter Five: Research Methodology

Key Concepts


Research Design
Conceptual Framework
Theoretical Framework
Operational Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
The method of measurement (simulation)
Testing reliability of measurement tool (internal validation)
Chapter Six
Methodology of analysis of Single Skin variables
Benchmark Single Skin Facade
Chapter Seven
Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
Induction into theoretical propositions
Chapter Nine
Chapter Five: Methodology

5 Chapter Five: Methodology and Operational Framework

5.1 Introduction

The aim of the thesis is to evaluate the thermal performance of double skin facades in a hot arid context as a façade refurbishment option to decrease dependence on cooling systems in office buildings, while maintaining users' comfort. The generalizability of the thesis extends to include all cities with a similar hot arid climate to Cairo, such as Phoenix in the USA, Rorkee in India, Adelaide in Australia and man cities in the Middle East such as Nigiv in Israel and Riyadh in Saudi Arabia. In Chapter One the context of the study was reviewed to understand the built environment and the climatic, social and historic constraints that led to the existence of office buildings within the context of Cairo. In Chapter Two the relation between the façade and the occupiers' perceptions and needs were discussed to understand their impact on molding façade configurations. In Chapter Three literature reviewed multi-layered facades typologies, with examples from the built environment that used multi-layered facade configurations for new built or refurbished buildings. The review provides a general platform to understanding refurbishment and available façade technologies. This chapter provides a discussion of the proposed methodology for achieving the aim of the thesis. The chapter starts by a literature review on research methodologies used in previous research to study building energy performances. Based on the knowledge gained from the literature review, hypothesis of the thesis are then formulated. Finally the chapter reviews methods to verify and quantify the relationship between façade technologies for refurbishment and impacts on energy consumption and users' comfort within the workplace.

5.2 Development of Research Methodology Relating Energy consumption to the built environment:

Reviewing literature indicated different research methodologies aiming at explanation building and establishing theories on how and why energy is consumed in buildings in relationship to the façade configuration. In this context it is useful to understand the evolution of methodologies in studying energy performances to identify the methodology to be used in this thesis. This is achieved by categorizing literature found according to year of publication.

Literature found dating back to the 1960s based on a scientific methodology can be divided into two main streams. The first research direction aimed at optimizing the relationship between the building and ambient climatic contexts (Olgyay 1963). The second mainstream of research was to drive the building away from climate by using advancements in building environmental systems. This stream of publications formed the backbone of development of guides on control of indoor climates by building services (ASHRAE 1963). However, the sudden increase in energy consumption and over reliance on mechanical equipment to provide occupant comfort is highlighted in research of the late sixties (Banham, 1969).

After the first Oil Shocks of the 1970's energy research was directed towards quantification of energy types and its use in buildings. By the late 1970, preliminary surveys of different types of buildings' and their energy consumption were published in the USA. Due to the strategic sensitivity of continuation of energy supply to the built environment, joint efforts between different governmental departments and research centers developed, such as the joint Energy Information Agency and U.S. Department of Energy publication on the 1979 non-residential building energy consumption and expenditures ((EIA) 1983).

The impact of energy shortage during the oil crises aroused several concerns that directly impacted on research directions, mainly in the fields of human comfort and alternative sources of energy. Research findings were then integrated to produce a series of building services design guides that are used and regularly modified to the present day by leading organizations such as ASHRAE (American Society for Heating, Refrigeration and Air-conditioning Engineers and CIBSE (Chartered Institute for Building Services Engineers).

Based on research carried out on human comfort dating back to the late 18th century, other aspects affecting human comfort criteria in spaces returned to focus. The field of thermal comfort was led by Fanger, (1970) and Humphreys' (1975), while other aspects of the workplace also came into consideration such as ergonomics and environmental psychology studies (Proshansky 1976). The research methods adopted varied between experimentation on subjects in closed rooms (Fanger, 1970) to observations and field experiments (Humphreys, 1975). Fanger's work adopted a scientific approach were variables were controlled and depending on less advanced instrumentation, while other work including field experiments integrated qualitative methods in assessing the results (such as Humprehys' work). The research outcome of this particular decade forms the backbone of ongoing research till the present date.

During the 1980's a profligate number of publications are found, ranging between energy surveys to developing methods and tools to predict end use loads. (Akbari et al. January 1989) quote more than 50 primary references on the subject. Using building energy simulation software, the bulk of research aimed at establishing the relationship between climatic indicators, occupancy types and varying building shapes. These indicators were developed based on large scale statistical samples including whole regions and States in the USA (Haung et al. 1986). These studies depend on the evolution of simulation software to forecast future utility demands. Predicted utility demands were generalized in a wider context to help support European and North American policies in securing energy demands for future generations. The result of these researches led to the production of standard load shapes and average building consumption loads on annual and peak load bases.

The early eighties introduced the relation between energy usage and human psychology, and sociology. These studies intended to help in the search for methods to reduce energy consumption in the built environment, while helping energy consumers to understand the behavioral changes needed and to recognize opportunities for reducing energy consumption without compromising human psychological needs (Baum and Singer 1981).

In the 1990's more survey results carried out in the late 1980 were published. Commercial building types were more into focus as a major energy consuming sector (Anonymous 1992; DOE/EIA 1992). Due to the realization of the diminishing energy resources and the environmental impacts of human activities, sustainability of the built environment and resources came into focus. Refurbishment for energy efficiency appeared in a number of publications and research findings were reported in the form of quantifiable economic return. However, these researches concluded that the cheapness of energy resources does not give enough incentive for energy consumers to reduce their energy consumption or adopt energy efficient technologies that do not give a quick economic return.

The 1990's witnessed an integrated research approach between the qualitatively measured nature of human comfort and productivity on one hand and the need to sustain the quantitatively measured diminishing fossil fuel demand on the other. The integration between various research methods and the interdisciplinary approach between the various domains led to the appreciation of the quantifications of the scientific methods along side the qualitative studies on human energy needs and comfort demands. Although, increasing human productivity and its economic return precedes any energy conservation concern is still the reality, research linking energy usage to human productivity and comfort still extended its efforts to verify the need to conserve energy and the environment (Clements-Croome 2000).

During the late 1990 and the start of the 21st century, the continuous increase in carbon dioxide emissions and the realization that climate change was already upon us and brought alongside many changes in building regulations aiming for an abrupt cut in carbon emissions and bring penalties to incompliant buildings. The British Building Regulations Part L has been reviewed in 2003 to minimize carbon emissions from the built environment.

This research builds upon the integration between the interdisciplinary domains of conserving energy while considering human psychological needs to construct the framework of the inquiry.

5.3 Research Methodology:

Reviewing literature, two distinct approaches for undergoing research in the domain of studying building energy performance are identified, the scientific approach and the naturalistic approach. A third approach is the integration between the two methods and is referred to in literature as the 'Integrated method' or 'mixed method'.

5.3.1 The Scientific Approach

The scientific approach is a method of attaining knowledge through a controlled systematic process. It is when science is recognized as not just a body of knowledge but a logic of inquiry, for generating, replenishing and correcting knowledge (Kerlinger 1986). The scientific methodology, following Karl Popper's proposed account of the logic of scientific inquiry, is built upon *'falsifiable'* hypothesis.(Burns 2000) Falsifiablity is the doctrine that hypothesis should be submitted to rigorous testing, where scientists should not be looking for confirming hypothesis while overlooking or ignoring events and observations which might disprove their theory.

Knowledge is gained by conducting experiments based on hypothesis. Experiments are linked to a structured process of sampling, identification of variables, elimination and control of variables and reliable measurements for testing these variables.(Lewis-Beck 1993)

The main strength in conducting experiments lies in precision and control. Through the systematic control of variables, experimentation leads to statements about causation, where a direct cause is linked to a direct effect of another variable. Therefore control enables the scientist to identify an event, why the event is happening, and under what conditions an event occurs.

The resulting quantitative data permits statistical analysis, thus confirming or refusing the hypothesis to be tested. If the hypothesis prediction are confirmed then the prediction is congruent with what actually occurs, but it does not prove that the hypothesis is true.

As any research method the scientific method has its shortcomings. The scientific method is not immune to biased to subjectivity in recognizing a problem for investigation, assimilation of data, casual explanation, deliberately or un-deliberately ignoring interpretations of unanticipated or uncongenial experimental results. These shortcomings must be kept into consideration and minimized by measures to insure reliability of collected data, and analysis.

The limitation of the scientific method is when testing hypothesis that interact with human beings. Huge problems are faced by researchers in education and behavioral science since human beings are far more complex than inert matter that is studied in physical sciences. This arises as human beings are not only acted upon by various environmental forces but tend to perceive, interpret and react to them in different active ways. Considering this limitation, no assumptions should be made to the truth or that all people are the same at all times (Burns 2000).

5.3.2 The Naturalistic Approach:

The naturalistic approach or non-experimental approach utilizes observational methods involving the collection of data with less direct manipulation of conditions and subjects (Gupa and Lincoln 1982). Data is usually collected through questionnaires, surveys and/or observations. The method is built upon opposition to the epistemology underpinning the scientific methods and those experimental assumptions leading to generalizations of outcomes, regardless of context or variable influences on the controlled variables. Advocates of this method criticize the scientific methods as driven away from studying the complex human nature, arriving at conclusions produced from tests carried out in controlled environments and rigid environmental control.

Also known as qualitative methods, naturalistic approaches aim at capturing people's aspirations and actions while allowing for the complexity and variability of human responses to their environments. Eisner (1979) defines the qualitative approach as: *'as concerned with process rather than consequences, with organic wholeness rather than independent variables, and with meanings rather than behavioral statistics'*. Burns (2000) describes qualitative research as characterized by *'methodological eclecticism'*. However the major limitation of this method from the advocates of scientific methods point of view is the lack of replicability of context, events and conditions thus conventional application of testing procedures' reliability or validity is difficult.

5.3.3 Mixing Methods:

In reality the strong dichotomy presented in most methodology books between the two main research approaches and the philosophical rational underpinning them is exaggerated. Burns (2000) criticizes this polarization as *'overdone and misleading, as both qualitative and quantitative research are empirical methods and both methods are concerned with observations and recording of the real world'*. In practice many researchers tailor the two methods to produce understanding of actual phenomena.

5.4 Proposed Methodology:

The thesis adopts a scientific method to test and refute hypothesis. The hypotheses are derived from theory linking façade architectural technologies to energy consumption in office buildings. Cairo is chosen as a case study. The nature of Cairo's climate being in a hot arid area maybe common with other hot arid areas but the patterns of energy consumption and façade configurations are built on specific socio-cultural and economic aspects underpinning the evolution of office building facades in Cairo.

To create a holistic understanding of the energy consumption of office buildings in hot arid climates in general and specifically in the context of Cairo, a triangulated data gathering method is adopted. Triangulated data refers to data gathered from different sources to compliment gaps identified in gathered information to create a holistic view that underpinning the research hypothesis. From previous literature and a cross sectional historical survey on office buildings in Cairo, the base case is created thus forming the unit of measurement.. The physical variables from the sample are mapped onto the Base case façades to provide façade thermal performance indicators.

Double skin facades are introduced as an architectural facade technology that enhances building environmental control. The double skin façade configuration is proposed as an option for refurbishing existing office building facades. It is proposed within this context as a possible architectural solution to minimize direct solar radiation into occupied spaces, thus reducing cooling loads.

Scientific method defined by (Ragin 1994) *'is when deduction and induction work together'*. To study the effect of varying double skin facade configurations on cooling loads a deduction method will be used. This deduction method is adopted to identify and categorize variables into dependant (controlled and static values) and independent variables (causing the effect).

To measure the impact of using multi-layered façade configurations on building cooling loads experimentally, dynamic software (APACHE) is used as the experimentation tool to generate data for statistical analysis. The choice of APACHE as a simulation tool is discussed in Chapter 6 in section 6.5. As a tool for experimentation, simulation software offers constant boundary conditions during experimentation. Simulation in the context of the thesis replaces laboratory testing to increase precision, repeatability and reproducibility of results. However, as a limitation in experimental work, the difficultly in assessing the level of truth in simulation results is evident as simulations only offers an approximation of the real world.

A limited reliability test is carried out to increase confidence in simulation results. Pedrini et al, (2002) and Carriere et al (1999) proposed a methodology for increasing reliability of simulation outputs by calibration of data input. Calibration of the software is performed by simulating an existing building in the warm climate of Brazil based on a three tier procedure. The three step approach is built upon

1- Analysis of building plans and documentations,

2- Walk through and audits

3- End-use energy measurements.

This methodology is adopted in this thesis to calibrate and check reliability of simulations output. A simulation of an existing building (World Trade Center) is performed. Analysis of building plans, sections and building services followed by a walk through was carried out in December 2000. End use energy measurement was substituted by comparison of the simulation output to sub-metered electricity bills.

An operational framework for analyzing variables affecting single and multi layered facades are discussed in Chapter 6 and Chapter 7 respectively. Due to the previously discussed limitation of the method of approximation to reality, data are analyzed parametrically. Analysis of simulation data is divided into five sets.

- The first set of simulations aims to identify a Benchmark Single Skin façade configuration to maximize the thermal performance efficiency of the single skin base case.
- The second group of simulations aims to identify a Benchmark double skin façade configuration.
- The third set compares between the Benchmark Single Skin and the Benchmark Double Skin (multi-layered) façade configurations to achieve minimum cooling loads and therefore maximize energy reductions through the façade configuration.
- The fourth set studies the effect of refurbishing a set of existing buildings' façade configuration with the benchmark double skin facades.
- The fifth set of simulations compares the daylight performance of the Benchmark single skin and the Benchmark Double skin to discuss their effect on occupants' comfort.

The choice to compare energy implications with both standard and Benchmark Single Skin is to test hypothesis stated by (Oesterle et al. 2001) that Double Skin Façades only seem to be producing remarkable energy saving when compared to 'antiquated' insulating standards, but for buildings based on low-energy construction standards, energy savings through a second façade layer will be quite limited. Therefore the analytical approach to simulation results is aimed at converting general expectations and intuitions on the performance of a double skin façade *(hypothesis)* as a new architectural technology in a hot arid area, into the grounds of understanding its performance based on research.

However, based on the scientific methodology adopted, the logical stream towards concluding on optimum façade technologies for refurbishment based on minimum energy consumption may lead to devaluation of individuals' needs from a building façade.

Therefore a method of induction starts by inducting information generated from the simulation of double skin facades to assess its implication on energy consumption into qualitative theories predicting human comfort aspects within the workplace. Three qualitative criteria underpinning the psychological comfort of occupants and its impact on productivity are set for balancing energy savings from the façade configuration with occupants' needs these are: the need for a view out, day light availability for non-task performances, and perceived control over the façade in work places.

5.4.1 The Operational Framework;

The operational framework is defined by (Nachmais and Nachmais 1992), as: ' *a set of procedures that describe the activities to perform and to establish empirically the existence or degree of existence of a phenomenon describing a concept.*' The detailed methodology of the construction of the unit of analysis, the measurement of variables is discussed in detail in the following chapter a brief description is included in this methodology chapter to facilitate understanding the research design as a whole.

5.4.1.1 The unit:

The study quantifies reductions of cooling loads in relation to façade configurations and façade technologies used in refurbishment. The unit of analysis in this context is the cooling load per a typical m^2 of a base case. The construction of the base case is a detailed process where the physical and operational profiles are deducted from a survey on the office buildings in Cairo and available literature, then mapped onto the simulation model.

5.4.1.2 The logic linking data to propositions

To link data to hypothesis the methodology of grouping variables, tool for measurement and methods of analysis are briefly explained in this chapter.

5.4.1.2.1 The variables

The variables affecting the thermal simulation are divided into dependant and independent variables. Nachmias (1992:54) identifies variables as an empirical concept; he states this relation as: *'Research problems are conveyed with a set of concepts. Concepts are abstractions representing empirical phenomena. In order to move from the conceptual to the empirical level, concepts are converted into variables. It is as variables that our concepts will eventually appear in hypothesis to be tested.'* The variables expected to explain change in the dependant variable are referred to as independent variables. The independent variable is the exploratory variable that causes changes in the value of the dependant variables.

In the context of this exploration, there are three sets of independent variables namely the climate profile, the building morphology, and building operational profile. These variables are not only based on literature but are deducted from a survey on office buildings Cairo (explained in chapter 6).

The dependant variables are concerned with alterations to the physical properties and construction of façade layers under the hypothesis of the thesis that would affect cooling/heating loads in office buildings in a hot arid climate, namely Cairo.

The dependant variable is the building façade configuration, looking at changing existing façade configurations on a conceptual model, whether these alterations are on single or double skin, to measure changes in building cooling loads.

5.4.1.2.2 The measurement tool:

To choose a reliable tool capable of predicting the thermal performance of single façade technologies and multi-layered facades in a hot and arid context, different measurement tools were reviewed. From literature found, four different methods to study the thermal performance of facades prevailed. It is prudent to mention that these methods are generally used to study the thermal performances of all different façade configurations, in the context of this study, emphasis are on methods used to predict and assess the thermal performance of double skin façade. Chapter Six illustrates these methods, their limitations and compares between their appropriateness for this study, finally explaining why building energy simulation is chosen.

A dynamic building energy simulation tool (APACHE) was chosen. The simulation code is intended for whole building dynamic modeling. It is used in this study in an attempt to emulate reality by creating the conceptual model, then attaching different variables acting simultaneously and interactively to influence various heat and mass transfer paths into the occupied office space.

5.4.1.3 Criteria for judging quality of research design:

To judge the Internal validity of data a base case model was created based on information gained from a survey on office buildings in Cairo and on previous simulation results carried out in hot arid areas on single façade configurations and on a study of the performance of double skin facades in Arizona (Afifi,1994),

External Validity is limited in studies of building simulations to those propositions underpinning the construction of the base case and the specifics of the simulated climate, urban context and the building's occupation patterns, equipment usage and building services required. However, the Benchmark Single and Double skin façade configurations identified by building simulation analysis are tested on various Window to Wall Ratio (WWR) configurations of existing façade configurations identified from the Cairo office building survey.

5.4.1.4 The criteria for interpreting findings

At this stage the thesis aims to assess the multi-layered façade construction as an architectural technology in terms of its energy savings, and assess reliability of simulation data.

5.4.1.4.1 Methods of analysis:

Simulation tools are used in research as a consistent quantifying mechanism to predict energy consumption of building. However, results are dependant on data input. Real buildings are complicated and variable systems. For simulation, assumptions are made (internal loads and systems performances) to reduce this complexity in to a manageable data entry level which means that results obtained are a realistic approximation of the real building. For the purpose of analysis, all simulation results are converted into EXCEL sheets where parametric analyses were performed. The model is divided into four equal zones facing the four major directions North, South, East and West. The simulation output provides monthly cooling/heating loads per each orientation. These loads are then divided by the area of each orientation zone to analyze the effect of a certain façade configuration alteration on the typical m^2 of the building in relation to its orientation. Results are then compared to the consumption per m^2 of the base case.

Analyses undertaken are divided in two sections; explain the variations between peak predictions for the cooling dominated season, and the annual cooling loads of buildings. The analysis are presented visually in the form of graphs within the thesis body.

Simulations were carried out on different façade technologies for refurbishing single skin to optimize its performance within the range of façade technologies specified in the thesis. The second set of simulations looked at using the same set of façade technologies specified for single skin but on a multi-layered façade construction (double skin façade).

The analysis finally seeks to compare cooling load reductions to the performance of the conceptual model (base case), a Benchmark Single Skin Façade and multi-layered façade configuration in relation to total cooling loads.

5.4.1.4.2 Reliability of data

Monitoring methods of existing double skin facades in a hot arid context was considered the preferred method to empirically validate simulation results. Monitoring would have created a base to evaluate modeling assumptions and to assess reliability of the simulation tool; however no double skin façade has been constructed in Cairo until the time of writing this thesis. To overcome this limitation checking the reliability of simulation results was carried by two methods.

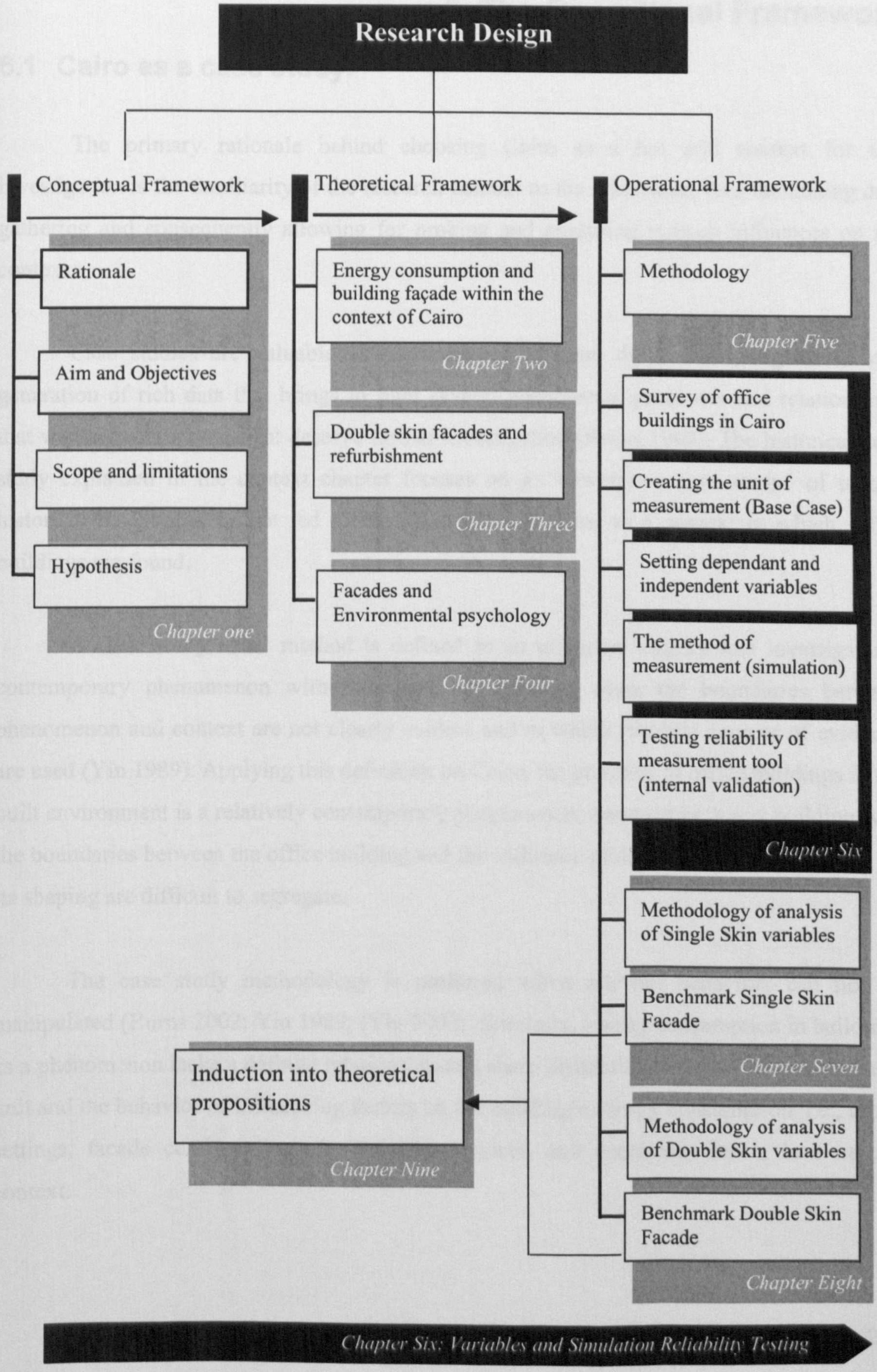
To test reliability of the simulation tool and the assumed variables triangulation of simulation results with actual electricity bills from an office building were carried out as the empirical validation of single skin simulation results. The availability of a considerable amount of load shapes relating to single façade configuration allows for pattern matching the load shapes from previous studies to those generated from this study.

To check reliability of double skin façade configurations simulations, results were pattern matched to previous research results carried out by the four measurement methods presented on research of double skin facades, and cavity walls. The next chapter illustrates and discusses the operational framework of the thesis in detail.

Chapter Six: Variables and simulation reliability testing

Key Concepts

6.1 Cairo as a case study
6.2 The unit of measurement
6.3 Test variables
6.4 Methods for examining the performance of double skin facades
6.5 The method of measurement
6.6 Testing reliability


Research Design
Conceptual Framework
Theoretical Framework
Operational Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
The method of measurement (simulation)
Testing reliability of measurement tool (internal validation)
Chapter Six
Methodology of analysis of Single Skin variables
Benchmark Single Skin Facade
Chapter Seven
Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
Induction into theoretical propositions
Chapter Nine
Chapter Six: Variables and Simulation Reliability Testing

6. The Operational Framework

6.1 Cairo as a case study:

The primary rationale behind choosing Cairo as a hot arid context for this investigation is the familiarity of the research context to the researcher, thus facilitating data gathering and consequently allowing for probing and analyzing various influences on the context.

Case studies are valuable as preliminaries to more detailed investigations, with generation of rich data that brings to light several phenomena, processes and relationships that would in their own right deserve further investigation (Burns 1999). The historical case study explained in the context chapter focuses on a *"descriptive case study"* of unique historical developments that led to the peculiarity of Cairo as a context in which office buildings are found.

A Case study as a method is defined as an empirical inquiry that investigates a contemporary phenomenon within its real life context; when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used (Yin 1989). Applying this definition on Cairo, the presence of office buildings in the built environment is a relatively contemporary phenomenon; however as in any building type the boundaries between the office building and the influence of different contextual forces on its shaping are difficult to segregate.

The case study methodology is preferred when relevant behaviors can not be manipulated (Burns 2002; Yin 1989; (Yin 2002). Similarly, energy consumption in buildings as a phenomenon lacks a definite relationship and sharp distinction between the building as a unit and the behavior of influencing factors on the building's energy consumption, i.e., urban settings, facade configuration, the building services, and occupancy levels in a certain context.

As illustrated in the context chapter, there have been context specific social, political and economic factors that affected the construction of office building façade in Cairo. It is the aim of this chapter to draw upon the conclusions deducted from the context chapter to analyze the particular energy consumption patterns in a selected sample of office buildings in Cairo.

Case study as a methodology for research has consistently been criticized of providing little basis for scientific generalization. However, case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. Like an experiment a case study does not represent a sample and the investigator's goal is to expand and generalize theories (analytic generalizations) and not to enumerate frequencies or statistical generalizations (Yin 1989). (Gupa and Lincoln 1982), called for replacing the concept of 'generalization' with the concept of 'fittingness' with emphasis on analyzing the degree to which the situation studied matches other situations. This approach necessitates an understanding of the context, with a logical consequence of emphasis on supplying a substantial amount of information about the entity studied and the setting of which this entity is found (Schofield 2000). Although a case study is valuable as a unique case in its own right that is worth documenting and analyzing. The performance of an office building façade in Cairo would be regarded as a *'fitting'* of an office building façade thermal performance in any similar hot arid climate.

The term 'Case study' is used in two distinctive instances. It is used to describe a 'unit of analysis or to describe a research method. 'Case study' is mostly used under the framework of qualitative research methods. In this context the case study is used as a research method. It is not used as a qualitative research framework but to provide quantitative evidence through a survey on the existing office building façade layers and configurations, and office building energy consumption. It is used as a method to describe the real life context in which the office buildings exist in a hot arid climate to explore if using double skin facades as a refurbishment option -as an intervention- has an impact on energy consumption of office buildings.

The objectives of the survey are directed towards exploring and gaining knowledge on the office building stock for two purposes:

- The first is to understand the common physical attributes of office buildings' façade construction in Cairo which in turn affects variables choices for the simulation model.
- The second is to find reliable energy consumption for a specific building, and use the information to validate the building simulation model results.

The following section explains steps towards achieving the objectives of the case study.

6.1.1 Survey design

To design the survey strategy, a clear definition of what is to be investigated was set. The definition of an office building within the context of the thesis is a purpose built office building that is solely occupied by office use activities. All other mixed used buildings- even if they include an office activity- are excluded from the sample. The purpose of a survey within a case study framework is to produce statistics, of quantitative and numerical descriptions of some aspects of the study population. Information is collected about only a fraction of the population which is a sample of the general population (Yin 2002). In this case study design the data collection covers the time period over which office space was needed in Cairo. This time period is from the late 19th century till the present date. The time frame looks at the evolution of office building facades since they appeared as a separate building entity in Cairo, to provide a wider perspective on the range of façade configurations used within this context.

(Figure 1) explains the investigation design and the methodology followed to create the façade configuration of the base case as the unit of measurement and to validate simulation results.

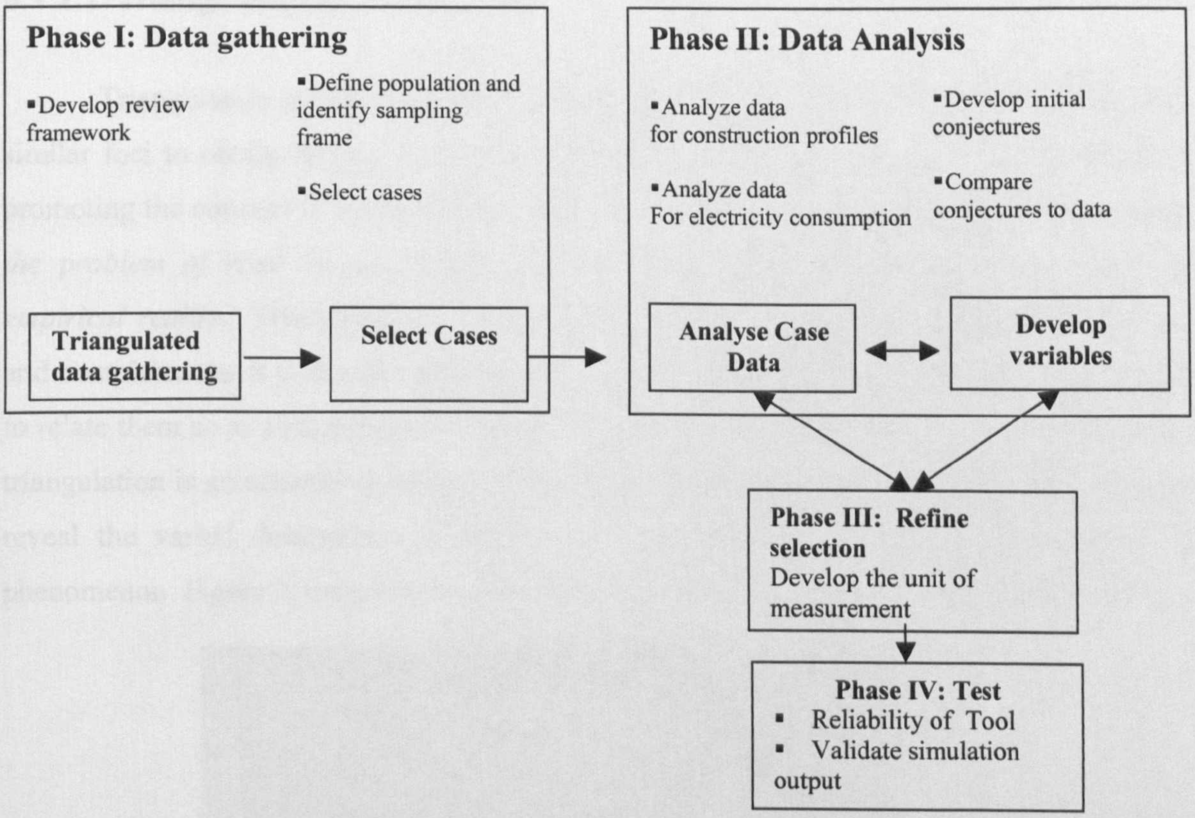


Figure 1: methodological process selecting a representative building (based on Lewis, 1998).

6.1.2 Data gathering:

The commercial building stock in Cairo contains a great variety of buildings in terms of size, location, façade design elements and building services systems. The choice to adopt a case study methodology on Cairo-Egypt stemmed from the need to explore how energy is used in office buildings in a hot arid context.

The aim of the survey is to understand the existing façade configurations of office buildings in Cairo; the objective of the survey is to deduct variables characterizing the existing façade configurations, and then induce these variables into the construction of a conceptual base case facade to be used as a measurement unit.

6.1.2.1 Triangulated data gathering:

Triangulation in data gathering is defined as the use of multiple data sources with similar foci to obtain diverse views through a range of data about topic. (Denzin 1978) in promoting the concept of triangulation argues that: *'no single method ever adequately solves the problem of rival casual factors...because each method reveals different aspects of empirical reality.'* Triangulation of data is used within the survey to provide confirmation and completeness. It is not the simple combination of different kinds of data but the attempt to relate them so as to minimize the threats to validity in each data gathering method. Using triangulation is an attempt to capture a more complete, holistic and contextual portrayal and reveal the varied dimensions of changes in office building façade configurations as a phenomenon. Figure 2, explains the data triangulation strategy adopted in for the survey.

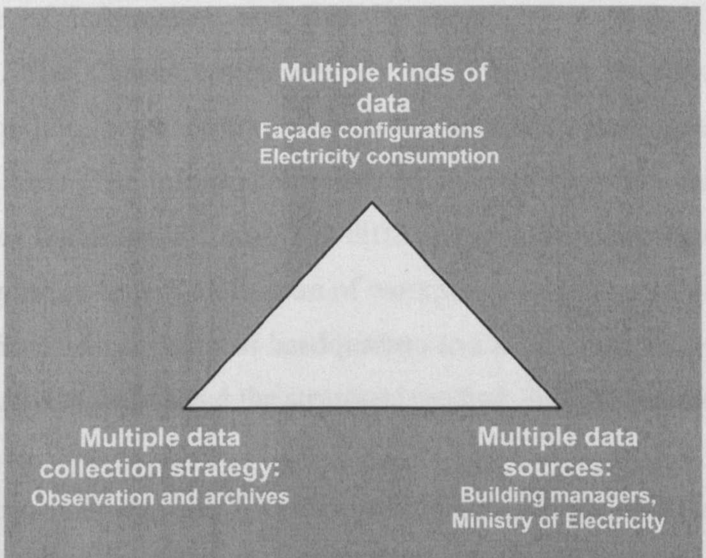


Figure 2: Data Triangulation

In this context data triangulation is used to understand the dominant constructs of buildings, within their real life context. This understanding aims to specify constructs of relevance to the creation of these buildings thus providing boundaries upon which guidelines for selecting a representative building façade is based. In preparing the stratified sample, buildings as constructs are chosen based on the frequency of inclusion of their façade characteristics within a certain time frame.

For collecting data on office buildings numbers and locations, multiple sources of information were identified prior to the survey (Figure 2), namely: The Centre of Information and Decision Support, the 'Egyptian Ministry of Power and Electricity', and previous publications. Two methods for enhancing information gained were identified, direct observations by a photographic survey of office building facades, and interviews with building managers to illustrate any changes that may have occurred to the building's facades.

Data gathered to assess electricity consumption in office building were collected from two sources, the first being through direct contact with building managers and the second from the 'Statistics Department' in the 'Egyptian Ministry of Power and Electricity'.

The Centre of Information and Decision Support provided 'The Egyptian National Census, 1996'. The Census categorizes the building stock based on grouping buildings according to building type (workplaces and residential), size, geographic location, and administration areas. The information provided was not directly useful into identifying the number of office buildings in Cairo. The difficulty in identifying data pertinent to the study from the census is the census' definition of workplaces including all commercial activities of whatever size from a large business headquarters to a small shop. However, data on structural methods were used to understand the structural methods used in building facades.

The Ministry of Power and Electricity divides buildings in relation to their electricity consumption into two groups, the residential and commercial metering groups. In the commercial metering group any building consuming more than 100,000 KWh/year is classified as a major consumer. However, this classification did not help in determining the number of office buildings within Cairo. Office space is classified under the main category of commercial activities. As explained in the context chapter the change of use of residential buildings to include banks, hospitals, restaurants and small scale industries in part of the building increased electricity consumption in these buildings. This rendered identification of buildings used as office buildings difficult. The complexities of metering added to the problem, in the majority of cases separate billing to separate space occupants were carried out and the only means to identify an office building was to get it's address then ask the billing department to add up all invoices from the same address. Adding the bills up was considered a costly and time consuming procedure which in most cases officials were not willing to take, expect in the case where a building was used by one owner or occupier. Information for four buildings were finally provided the Ftouh Tower, Cairo Barclays building, Cairo Sky and Arab African Bank Building.

The only sources for aggregating information on the office stock were previous publications, a photographic survey and open ended interviews with building managers. Scheduled meetings with building managers of the World Trade centre, Cairo plaza, Enppi, Ftouh Tower, Banque Misr and Nile tower were carried out during December 2000.

Previous publications surveying the office building stock in Cairo were reviewed (Afify 1987); (Ahmed 1999; Ibrahim 1998). The buildings surveyed in these publications were aggregated and formed the bases for forming a list of buildings to be included in the sample frame in this thesis.

Field visits were important to produce an objective and well- informed description of building to be included in the survey sample. However a walk through the commercial district of Cairo to undergo the photographic survey revealed other office buildings that were not included in previous literature, such as Misr National Bank, Barclays Bank building and two recently constructed buildings in Mohandeseen district, the national newspaper administration building Al-Ahram, the syndicate of artists building, El-Hezb building, and the TV and Radio broadcasting Building.

The purpose of the photographic survey is to describe the range and variations of façade configurations used to moderate energy flows through the building envelope in office buildings in a hot arid context namely Cairo.

- The maximization of daylight (window to wall ratio)
- Protection from the sun (louvers, internal or external blinds)
- Insulation (fixed, or movable wooden shutters)

- The rejection of direct radiation by overhangs and brise soleil.
- The exploitation of passive cooling elements (such as ventilation chimneys or double skin façade configurations)

However the random sample of buildings chosen gives a longitudinal view on the characteristics of office building facades in Cairo. Finally from all data sources used 37 buildings were chosen for their conformity with the definition of the office building within this thesis.

6.1.2.2 Selecting cases:

To select samples, buildings were excluded for their inconformity with the thesis definition of office building; if used as shopping centers or mixed use residential office space. However due to the data gathering limitations all office buildings found confirming the definition of the thesis were compiled as a sample frame. The sample in this case is a census of all office buildings found from different data sources to create a pool of potentially useful cases for analysis. Triangulation between different data sources; namely previous publications, the photographic survey and familiarity with the context provided a random but diverse sample of existing office building.

6.1.3 Data Analysis:

This stage explains the strategy used to analyze the coherent case data both within and across cases to detect patterns and to develop an understanding of the underlying constructs that caused changes to office building facades in Cairo.

The sample frame included a list of 37 buildings. As explained in the context chapter purpose built office buildings are mainly found in three main areas, in the modern quarters of Cairo, along the Nile in regenerated areas such as Bolaq (World trade Centre and Cairo Plaza Towers), and in the satellite districts.

The sample then was used to analyze two distinct characteristics of the existing office building stock:

1. The architectural configuration of facades; window to wall ratio and façade layers (37 buildings).
2. The electricity consumption of office buildings (10 buildings).

A final stage of analyses was to link electricity consumption to setting criteria for an existing building to be used as a pilot model for validation

6.1.3.1 Construction Profiles of facades:

To analyze the gathered data, a method of categorizing buildings into a stratified by age sample was adopted to represent different façade layers built in different eras thus producing a matched control group.

As the context chapter explained the built environment in Cairo has largely been influenced by land availability, construction methods, economy of the state and the image the political rule wanted to convey to the world.

This understanding helped in preparing a stratified sample based on the age category of the buildings, while providing insights to its evolution from a real life context perspective.

The façade image and technology transfer into the Egyptian context is divided into:

Buildings from 1882-1954 (Royal Cairo- Free soldier revolution 1953)
Buildings from 1955-1964 (Republic rule, nationalization of assets)
Buildings from 1965-1974 (War period, public funds directed to army re-enforcement)
Buildings from 1975- 1984 (Open Door policy, Sadat Assassination-until economic stagnation and rapid government debts)
Buildings from 1985 till 1994 (rise of economic debt-1991 economic reform program)
Buildings from 1995 till now (Introduction of advanced glazing).

In the absence of previous studies to categorize the office building stock from a façade thermal performance perspective, an explanation building method was used in conjunction with a time analysis method (division of buildings according to their construction decade) to understand the evolution and prevailing use of building materials, construction methods and window to wall configurations for facades.[1]

To find a representative window to wall ratio, buildings were categorized by their construction date. Each category is marked by closure at the point of a theoretical saturation; when marginal differences are identified from analyzed sample and the façade configurations become repetitive.

To find representative opaque façade construction materials, statistical data on building construction materials, survey data on 'places for work' in Egypt as defined in (CAPMAS 1996) are analyzed. The survey categories building materials for buildings by intervals of 10 year since 1960-1990 were analyzed. The analysis output is also fundamental to *determine* the range of *single skin façade alternatives* to be studied by simulation (Figure 3).

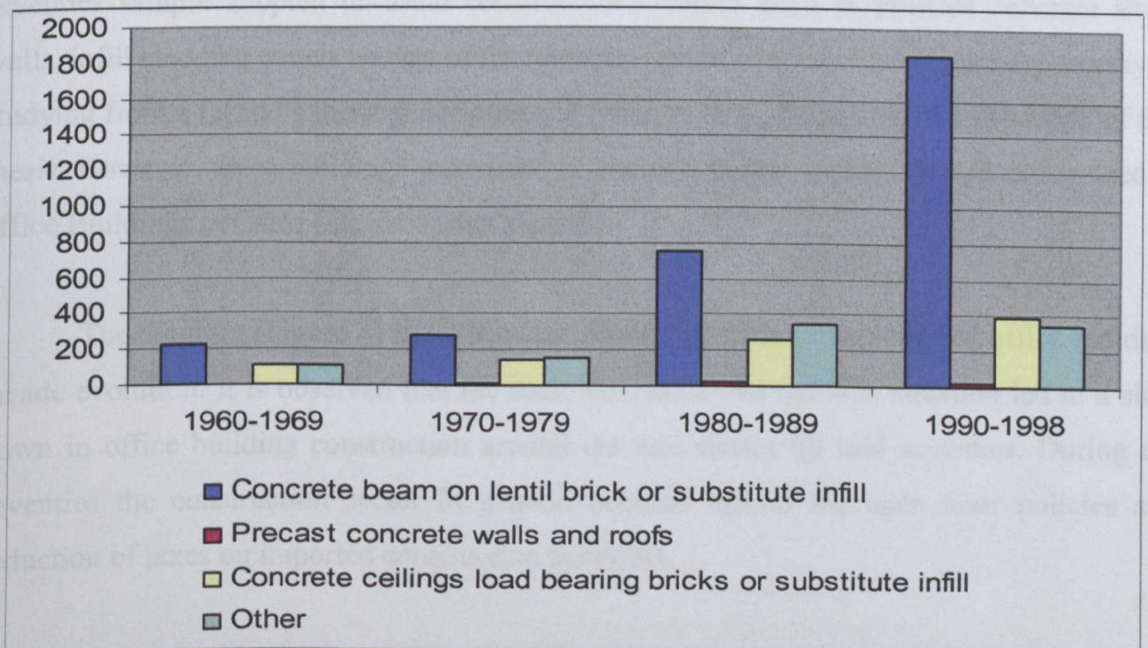


Figure 3: Building materials for public buildings in Egypt 1960-1996.

[1] Explanation building is defined as explaining a phenomena prevailing in a particular case.

The data provided by CAPMAS in this case should be treated with care as the columns do not represent the number of newly constructed, demolished or change of use buildings. The data conveys the number of existing buildings during the time of counting the four censuses. The data however is useful in indicating the general trend of façade layers. Regardless of age, analyzing the data indicates two prevailing types of construction; load bearing walls or concrete frames with bricks infill. Prefabricated concrete shear wall systems or steel mainframes construction is found to constitute a minor percentage of the construction of public buildings in general. The data presented as 'other' indicates a small number of buildings with wooden roofs or other materials that are of temporary nature. These buildings are outside this thesis scope as for their temporary nature they do not satisfy the definition of a purpose built office building.

Architectural drawings of façade sections were provided during open ended questionnaires with 14 building mangers but restricted for on site viewing only. These observations were used to confirm the general trend of building material and layers of façade construction from the CAPMAS data. It was observed that some office buildings by the late seventies sample adopted un-usual construction methods such as pre-cast concrete sheer walls, infill cladding panels instead of the usual un-insulated brick. These cases are worthy of studying from a façade's thermal performance point of view, but are outside the scope of this thesis. However, these buildings were used in analysis of the window to wall ratios used in office Buildings in Cairo (façade design aspects).

The diagram (Figure 4) links between context specific influences and office building façade evolution. It is observed that the socio-economic and political situation led to a slow down in office building construction around the mid sixties till mid seventies. During the seventies the construction sector in general boomed due to the open door policies and reduction of taxes on imported construction materials.

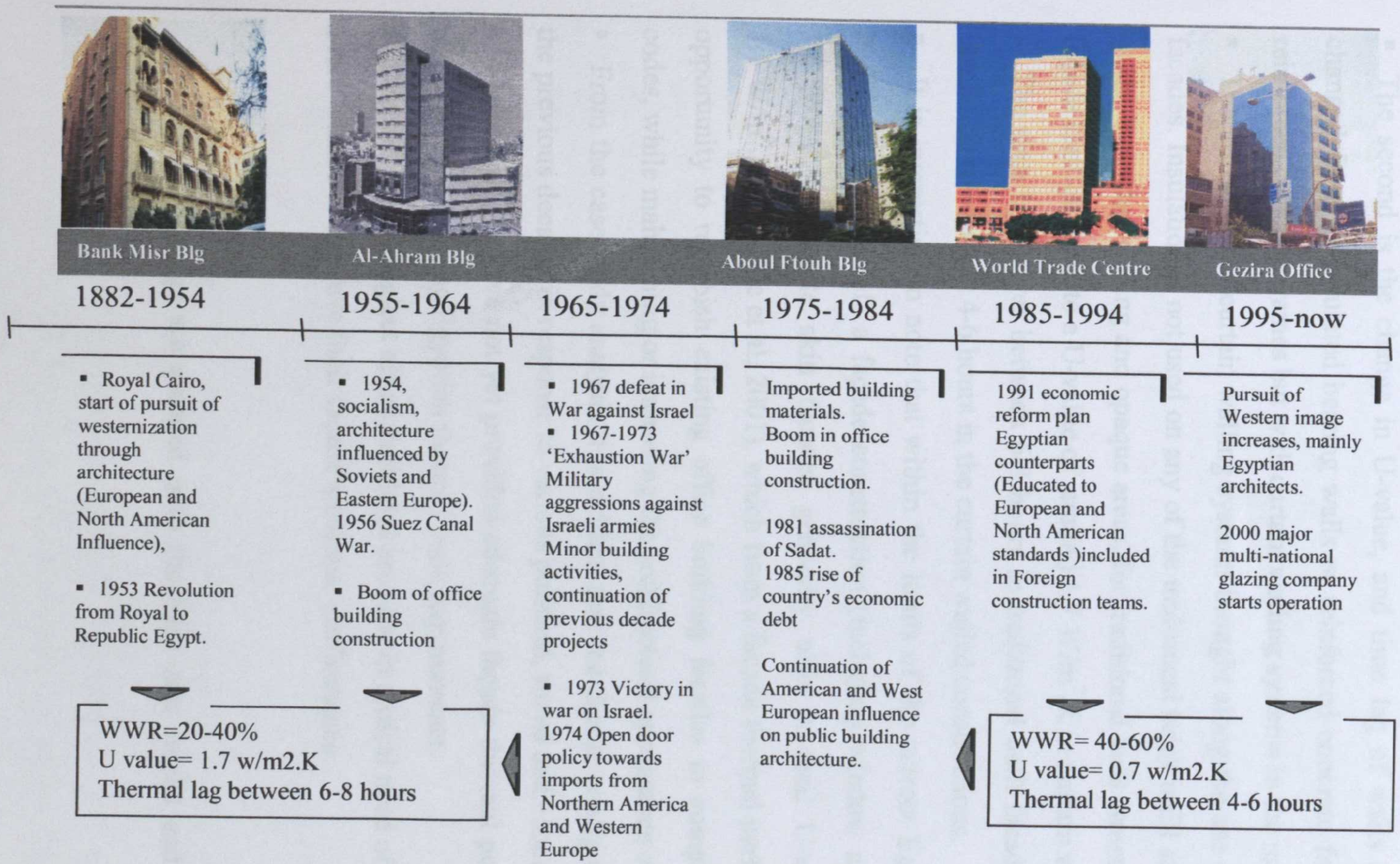


Figure 4: Evolution in Facade Design in relation to socio-economic, and political influences in Cairo

(Figure) indicates two major trends in façade evolution.

- The first is the increase on Window to Wall Ratio from between 20-40% till mid 1950's increasing to between 40-60% in the following decades.

- The second is the change in U-value, and time lag of walls as construction methods changed from un-insulated bearing walls or reinforced concrete frame with brick infill, to reinforced concrete frames but with curtain walling systems in the mid seventies onwards.
- The utilization of curtain walling systems brought along the use of insulation materials to facades. Insulation is not used on any of the traditional brick infill structures. The U-value of walls, including glazing and opaque areas, for traditional built structures is $3W/m^2.K$ for the façade configuration to a U-value of around $1.7\ W/m^2.K$ in curtain walls.
- The time lag ranges between 6-8 hours in traditional built facades of brick infill and no insulation to between 4-6 hours in the curtain walled constructions.
- It is interesting to note that within the limits of the current Egyptian thermal code for buildings the limit of a façade construction (including window areas) should not exceed $1.5\ W/m^2.K$. Double skin facades generally offer a total U-value for walls around $1.1\ W/m^2.K$ (Oesterle et al, 2001), which from a façade thermal performance angle offers an opportunity to refurbish existing office building facades to comply with current thermal codes, while maintaining or improving the architectural appearance of buildings.
- From the case study analysis it is evident that the façade configuration has changed over the previous decades in response to various political, social and economical influences.
- These changes have not yet provided adequate façade thermal performance in relation to compliance to existing Egyptian thermal code requirements.
- Due to age and neglect office buildings are now in critical need of refurbishment, which is a rare chance to improve their façade's thermal performance.

These findings are mapped onto the base case model and discussed later in this chapter.

6.1.3.2 Electricity consumption in Office buildings

The use of multiple sources for data collection allows for the investigation of a broader range of historical, attitudinal, and observational issues. In this manner the potential problem of construct validity is also addressed as multiple sources provide multiple measures for the same phenomenon. The use of multiple data sources is highly recommended and is considered as evidence that enhances the overall quality of information and increases its reliability (Burns 1999; Pedhazur and L.Schmelkin 1991; Yin 1993)

To improve the reliability of electricity consumption data, multiple sources of information were approached. A range of data collection methods; open ended questionnaires for building managers, observations, records collection for electricity bills and architectural drawings of buildings. The data collected is also used for triangulation to validate both prepositions for constructing the simulation model and simulation results.

The open ended questionnaire with building managers focused on:

- Operational Hours/ days of the building
- Air conditioning/ heating systems in the building
- Electricity metering and readings availability
- Electricity metering periods
- How occupants were charged for building system operation and electricity consumption.
- Archival architectural drawings of the building.

Data gathered were analyzed to provide a base for validating a pilot energy simulation.

The aim of collecting billing information and understanding the methods of meter reading is to:

- To understand the electricity consumption in response to the climatic profile of Cairo
- To use the result of building electricity consumption to validate and calibrate the simulation software used.

- It is important to mention that there are no privately owned electricity companies operating in Egypt and all electricity billing is controlled by the Ministry of Electricity and its branches in each city.

- Electricity billing systems were found to differ between buildings. Office buildings used for governmental offices for its different ministries were billed quarterly (every 3month), In the business sector, office buildings used for private and international companies were billed monthly.

Monthly billing systems differ significantly from one building to another according to the building management system. In cases where buildings were owned/ rented by a single owner all electricity meters of the building were compiled and billed monthly (such as Oil company headquarters Enppi and bank headquarters such as Cairo Tower and Cairo Barclays buildings).

In Cases of multiple tenancies two systems were found. The first is compiled electricity meter reading charged to the owner company (example: Nile Tower, World Trade Centre); the building manager would divide the bill quantity depending on the area occupied by each individual organization or company. The second method is occupiers having separate electricity meter readings and pay individually therefore deal directly with the electricity billing company (not through building management)

Based on findings of the survey, the first phase of analysis set criteria for data to be used for electricity consumption analysis. Office building electricity consumption data were eliminated if (Figure 5):

- Where building managers were not involved in meter-readings for leased parts of buildings where electricity used in the leased areas were billed to each lessee directly from the electricity company.
- Electricity was billed quarterly
- Whole floors un-occupied.

- The lack of a central control system for building mechanical systems
- Buildings depending on wall mounted or split systems for air-conditioning as this indicates independent use of the split units by occupants.
- Split units' date of installation and maintenance profile are almost impossible to track down.

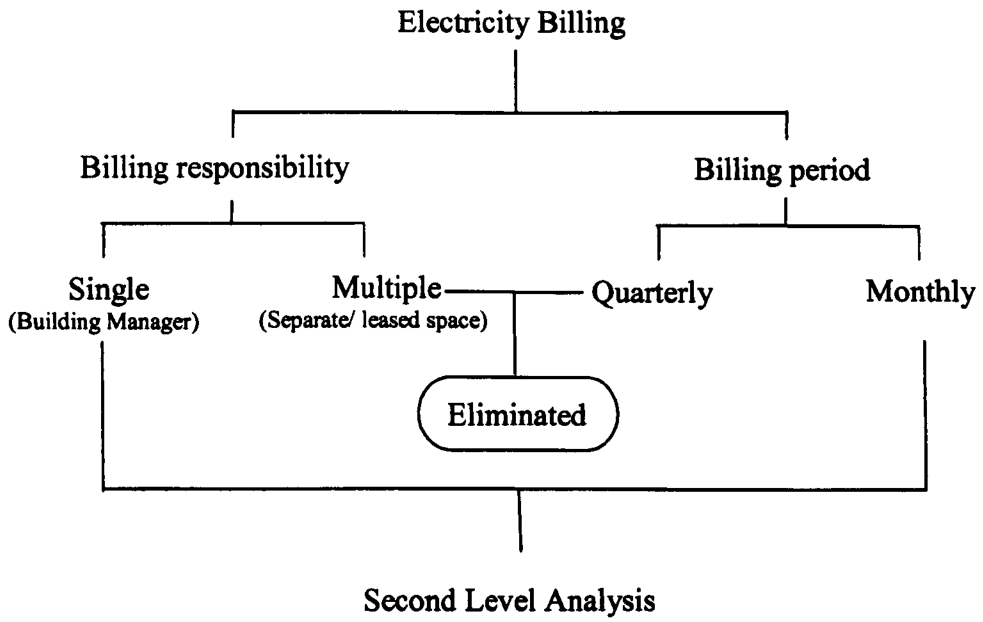


Figure 5: Process of elimination of data based on billing systems and periods

Based on the set criteria, all governmental offices, and part of the privately run office buildings were eliminated. The process of elimination left only 10 buildings to be analyzed from the original 37 buildings sampled for the building construction profile.

- Electricity bills collected from 10 buildings for a 3 year billing period were averaged and cross examined with the same information provided by the Department of electricity consumption in the Ministry of Electricity. The ten buildings' electricity consumption was then analyzed (Figure 6).

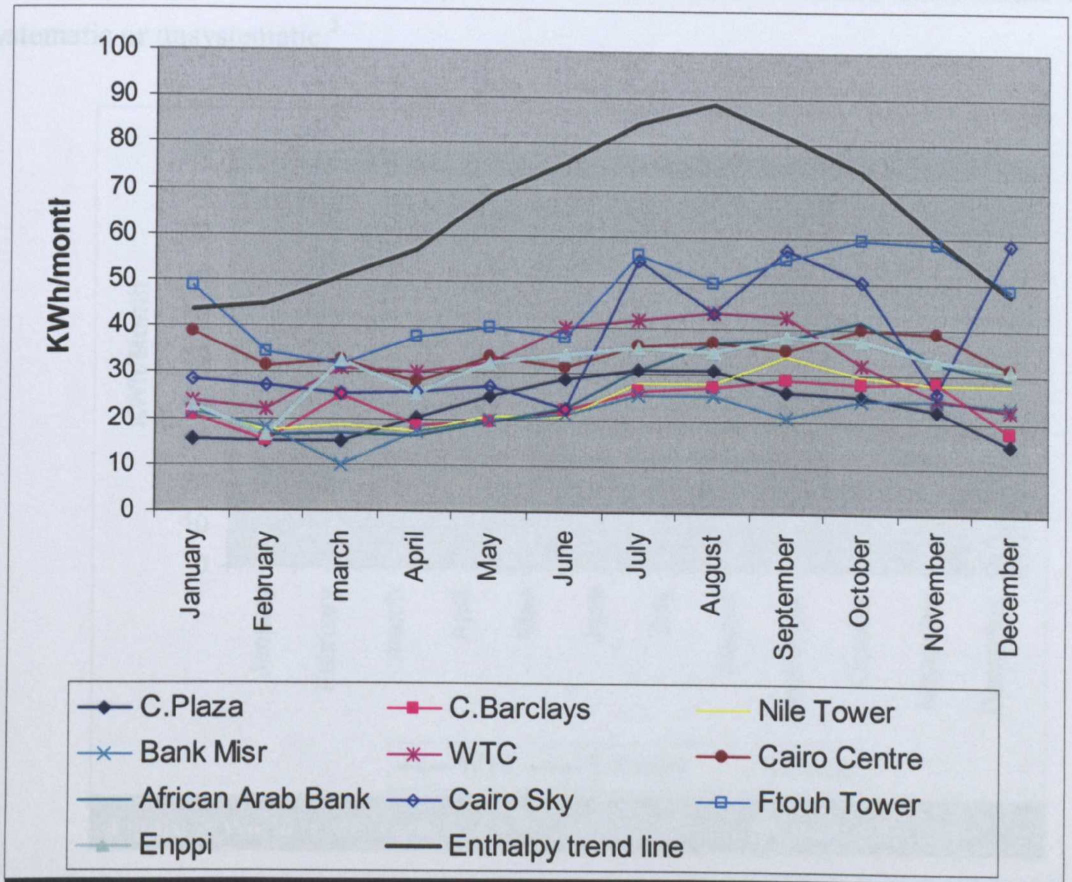


Figure 6: Annual Electricity Consumption for the sampled buildings

To facilitate the use of data to test the reliability of simulation results, building electricity load shapes are matched to the enthalpy trend line. The enthalpy presented on the graph is not a quantitative measure, rather a trend line that would combine both the effect of humidity and dry bulb temperatures of the ambient climate. The large variation of energy use between the surveyed buildings limited the choice of buildings for further analysis.

Two buildings of the sample, namely World Trade Centre, Cairo Plaza, indicated comparable and consistent electricity consumption pattern matched to the enthalpy curve shape (Figure 7). The other 8 buildings indicated inexplicable increases/decreases in consumption that maybe attributed to sudden increases/decrease in occupancy, failure of building systems or more erroneously to the mistaken readings of meters that were corrected by carrying consumption values over to other months of the year. At this stage judging the errors in data becomes more complex as it is not known whether these errors may be systematic or unsystematic.[2]

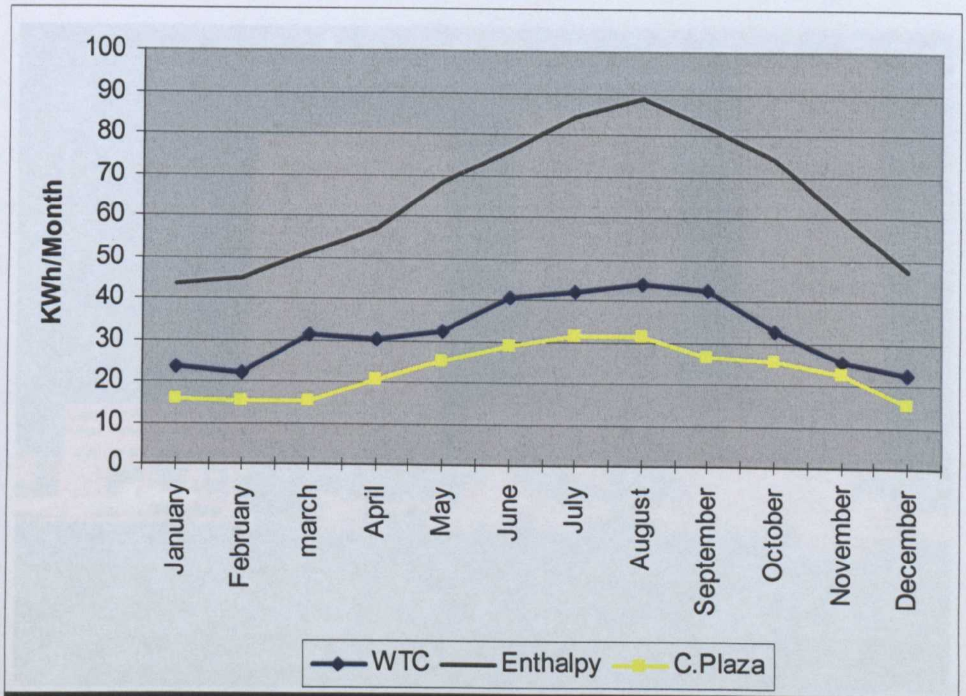


Figure 7: World trade centre and Cairo plaza electricity monthly electricity

To choose which building of the two to simulate to validate simulation outputs the following criteria were set.

- Un-shaded façade by louvers or other systems that increases the probability of assumptions in the thermal model.
- The building plan is a square thus indicating climatic influence on all facades and disregarding the effect an elongated plan in a certain orientation on cooling loads.
- The building should be free standing so without shade from neighboring buildings.
- The building should be recently constructed, thus less deteriorated facades that might contribute to implications on the building cooling load (i.e. infiltration problems).
- Building management controls all billing in the building.

[2] Data reliability refers to the degree to which test scores are free from errors of measurement (Babbie1998). Errors in measurement are either systematic (repeated in every measurement) or unsystematic (random and unpredictable upon repeated measurement) Pedhazur, E., & L.Schmelkin (1991) Measurement, Design and Analysis: An Integrated Approach, lawerence Erlbaum Associates Publishers.

- Separate electricity meters are used for cooling system, elevators, and general electrical use, to facilitate validation of software outputs.

Figure 8: Cairo World Trade Centre designed by SOM. It comprises a commercial podium, two towers for hotel accommodation. The third tower (to the left) is the office building used for the pilot model

Both buildings had a perfect square plan, recently constructed, a central building management system, and separate meters for building services. But Cairo Plaza is covered by transparent sun shading separated 0.8m from the façade.

World Trade Center is used to validate the simulation results. Although constructed recently in 1991, it follows the main theme of construction layers of office building facades in Cairo. It uses around 5,000,000 KWh/year and therefore is classified as a major electricity consumer (Figure 8).

6.2 The Unit of Measurement:

Chapter Five explained in general the concept of creating the unit of measurement. This chapter explains in detail the methodology underpinning the construction of the base case model as the unit of measurement and how it is used to quantify changes in cooling loads in relation to the building façade.

The construction of a base case model is considered the spine of building energy consumption studies. Nachmais and Nachmais (1996:44) define a model as *'a representation of reality. It delineates certain aspects of the real world as being relevant under investigation, it makes explicit the significant relationships among the aspects, and it enables the formulation of empirically testable propositions regarding the nature of these relationships'*. This definition looks at the model as an empirical phenomenon presented in logical arrangement indicating relationships between variables. The essence of creating a model is to abstract reality in order to simplify complex reality relationships between variables into a representation of reality's essential characters.

The number of base cases used (prototypes) in research depends on the size of the investigation and the research questions asked. In literature a single base case model is normally used. However there are studies that used several prototypes simultaneously in the same study. (Akbari et al. 1989) studied the USA commercial stock in general, including offices, hospitals, schools, prisons, hotels, restaurants, supermarkets, apartments, and retail stores. The study based on an extensive literature review of previous attempts in various climatic regions in the United states described 481 prototypical buildings used to develop a building load data base for assessing cogeneration market potential in 20 market areas.

Base case model are constructed to ensure;

- All effects in the model can be estimated and related approximately to previous predictions or results of monitored buildings.
- The effects of random variations can be easily tested
- Ensuring that all effects of changing the dependant variables causes least possible bias, and reduces the effect of time dependent errors.

Base case building models (also known as reference buildings) are used either to predict building energy consumption of whole buildings or for predicting energy consumption per m^2 of a plan area for a given duration of time. Time durations vary in literature between annual, seasonal or peak consumption predictions.

6.2.1 Base Case Morphology:

In literature, two main stream methodologies underpin the construction of a base case morphology. The two methodologies divide the definition of a base case into, the existing base case and the conceptual base case.

The first methodology is based on simulating alternative measures to improve the envelope heat transfer performances on an existing building (Nilsson et al. 1994). This methodology uses the existing entity of the building as a model base case. Building thermal zones are simplified to fit the selected software capabilities. Care is taken that modifications have no significant differences between present floor area, exterior wall area and orientation compared to the actual geometry of the building.

The second methodology is to construct a conceptual base case. A base case in this case is a prototypical building defined as a synthetic building compiled from statistical data from building surveys, and/ or conclusions from previous studies. From its definition a conceptual base case is not a real building, but a hypothetical construct with size, shell construction, window area, HVAC systems, operating and occupancy schedules based on the mean or prevailing conditions among surveyed building samples (Haung, and Franconi, 1999). The morphology is optimized and controlled as a simulation variable to study different façade configurations. The conceptual base case is used to examine different scenarios for improving building energy performance where results are generalized and extrapolated to a wider built environment in a specific climatic context (Afifi, 1994, Akbari, 1989, 1994). Hypothetical building models are also used to test drive new technologies or new building fabric alternatives that would have been expensive to build and time consuming to test (Lam 2000). This methodology is used to construct the conceptual base case used as the unit of measurement in this thesis.

To construct the three dimensional aspects of a base case morphology four aspects are considered, the level of model abstraction the floor plate aspect ratios, conditioned to non-conditioned space, and number of floors in the model.

6.2.1.1 Level of Model Abstraction:

The level of model abstraction refers to the level of representation of building services, architectural details and indoor partitioning of spaces. To construct the base case the three previous aspects are analyzed. The level of abstraction ranges from purely conceptual to fully explicit (Table 1).

It is worthwhile noting that a single model can be conceptual in one aspect and explicit in the other.

Table 1: Building services abstraction levels(Hensen, 1995)

Level	Type
A (room thermal processes, ideal plant) *	conceptual
B (Systems wise in terms of real systems)	
C (Component wise in terms of ducts, fans and pipes)	
D (subcomponent level in terms of integrated parts of system performances)	Explicit
.	

Building services abstraction level:

Level A: assumes an ideal plant system in its response to rooms' thermal processes and internal loads, where there are no losses of energy on start up operations, or fluctuations in energy performances to deliver cooling or heating to the building zones. Thus energy use is approximated by converting the room load to plant energy consumption using average system efficiency. However this level is not suitable for buildings with heating and cooling systems combined as it does not account for mixing losses.

Level B: Assumes a nearer to reality mechanical system where energy losses from main system components and system fluctuations to stabilize indoor thermal conditions are taken into consideration, but no energy losses are assumed in ducts, pipes or fans.

Level C: Simulates every part of the mechanical system with its actual performance. Components and their dynamics are modeled in detail (such as thermal inertia and cycling losses). This level is considered necessary to explore stability of local controls or to understand maintenance implications.

Level D: is a comprehensive model where the performance of other building services is integrated with the mechanical system performances. This integration of system simulates expected reductions/increases in internal gains that occurs dynamically during the course of the day in response to the changing outdoor environment

The façade level of abstraction is divided into four levels:

Level A: where façade configurations are simplified into the direct relation between glazed and opaque areas (Window to Wall Ratio WWR). Glazed areas may be divided into glass and framing areas.

Level B: where fixed façade details are taken into consideration such as recessed windows or walls.

Level C: Manually moveable facade details are included such as curtains and shutters

Level D: where automated and dynamic façade components responding to the climatic forces are modeled, such as retractable sun shading systems, and electrochromic glazing.

Indoor partitioning:

Level A; Open plan zones no partitions

Level B: Only solid and ceiling height walls are modeled to include their thermal mass in calculating rooms' thermal responses.

Level C: moveable and fixed partitions are modeled.

Level D: Where certain rooms or zones integrate dynamically with building systems, such as rooms nearer to the façade having electric light dimming systems.

(Hensen 1995), recommends that for purposes of researching on the thermal performance of building envelopes and the related building energy consumption, that the base case be constructed as a conceptual model, where the relation between the Building and its internal configuration and systems is simplified to decrease the number of the model blocks. Increased number of blocks may lead to unnecessary CPU usage and software instabilities. On the other hand, (Pedrini et al. 2002) recommend using an explicit model when a specific building is the focus of the study, to reach nearer to reality decisions on building services in relation to a building's architectural design.

As the study aims to look at the relation between the façade configuration and cooling system in a hypothetical building, the thesis proposes the construction of a level 'A' conceptual model with a level B building services abstraction level.

In the context of the thesis, all zones are assumed to be an open plan office, as the internal configuration of partitions is constantly changing according to organizational theories of space division such as beehive, den, and hot-desking. The previous theories advocate flexible interior spaces that maybe changed in accordance, but the open plan office is still the recommended trend. Partitioning the space affects the distance between the occupants and the façade and air-circulation in the space, due to the sizable scenarios that maybe generated if indoor partitions are studied and due to the time limits this variable is controlled in the conceptual model to a part cellular division in which the office space area is divided into four zones each facing a compass orientation. The building services are assumed to start one hour earlier than building occupation to reach required levels of room temperatures.

6.2.1.2 Floor plate aspect ratio

The conceptual models broadly used in building simulations may be divided into models of a square or rectangular plan with varying aspect ratios. Both plan configurations are found within the context of Cairo.

The aspect ratio combined with building orientation has an effect on the thermal performance of building facades. (Mahdavi et al. 1996), indicate a 5% increase in energy consumption when surface area of the base case model is increased from a square to a rectangular floor plan. In the context of the thesis, literature was reviewed for an optimized aspect ratio for the base case in order to control the effect of building orientation and aspect ratio on simulation results.

To construct a representative floor plate aspect ratio on a conceptual model, Briggs et al (1987) followed a cluster analysis methodology to categorize and derive a statistically valid sample of office buildings in the United States. Twenty categories or clusters were defined on basis of their physical attributes such as size, age, location, and building energy loads, these attributes were used to define simplified building model configurations upon which the different thermal attributes of the façade, occupancy, and lighting were imposed. A building aspect ratio (plan width to plan length) was set for the value of 1:2 for all the different categories to be modeled. The authors did not justify their choice for this particular aspect ratio and although it was stated that a '*building with an aspect ratio of 1:2 has about 6% more wall area per unit floor area than does a square in plan*'. It is not clear why this particular aspect ratio was evaluated as a necessary assumption for building simulation. It is however mentioned that a rectangular form was seen as more representative of the existing office stock as was indicated by results of the cluster analysis. Due to the elongated aspect ratio of the plan it is difficult to differentiate whether the energy consumption is due to the model orientation or due to its inherent characteristics and operational profiles.

Based on these conclusions literature was reviewed for other available models and studies that were used to predict energy performances and were based on an optimized building form particular to an air conditioned building in a hot arid climate.

(Sahu and Prakash. 1979) based on routine mathematical calculations, recommended that the building form for multi-storey buildings in a hot arid climate should be pyramidal, cylindrical or square with minimum dimensions of 28m*28m. The study concluded that the square plan with configurations below 28m*28m indicated wide fluctuations in heat gains from facades, while dimensions above this were recommended for least solar heat gain. In later simulation based studies, the aspect ratio of 1:1 (representing a square floor plate) with different variations in dimensions have been used, namely between 27m*27 m-to 45m*45 m have been used in many simulation based studies as a base case (Chow and Chan 1995; Lam 2000; Mahdavi et al. 1996).

In this study a base case square plan 30m*30 m was chosen as existing buildings with square plans are generally found to be within this range. This would also facilitate the validation and calibration of model as will be explained in the validation section later in this chapter.

6.2.1.3 Percentage of air-conditioned to non air-conditioned space

The model abstraction must also determine the percentage of conditioned and unconditioned areas which would implicate the level of energy consumption. As no Egyptian survey or studies were found to study this aspect, the British DETR classification was used. Purpose built Office buildings in Cairo are mainly designed by international and national teams and based on European and North American theories of office space utilization. From walk through observations, and reviewed architectural drawings, the service cored varied between 15-20% of the plan area. The DETR classification maybe adapted to the Egyptian context. The values suggested by DETR are used for estimation studies and prediction of energy consumption but if precise comparisons are required then measurements from the scale plans must be used.

DETR (1998)Table 2, classified the office buildings into four generic office types:

- Naturally ventilated cellular
- Naturally ventilated with open plan
- Air-conditioned standard
- Air-conditioned prestige

▪

Table 2: Energy Use in Offices, Energy Consumption guide 19. London, Department of the Environment, Transport and the Regions DETR (1998).

Type	Naturally ventilated cellular	Naturally ventilated open plan	Air conditioned standard*	Air conditioned prestige
Size	100-3000 m²	500-4000 m²	2000-8000 m²	4000-20000 m²
Purpose built	Converted from residential	Purpose built	Purpose built	Purpose built
Local controls	Used to reduce individual billing	Lights and shared equipment switched on for longer periods	Longer use of building services normally controlled by a building manager	Longer use of building services normally controlled by a building manager
Floor plan	Cellular	Open plan with some cellular	Larger open plans and less cellular spaces	Less space than category 3 used as office space leaving more open areas for restaurants and facilities, and more spaces for cellular offices
Net % of lettable areas	80%	80%	80%	80%
Treated floor area of gross	95%	95%	90%	85%
Net % of gross	76%	76%	72%	68%

Notes:

Gross internal area (GIA): is defined as total building area measured inside external walls.

Treated floor area (TFA) gross area less plant rooms and other service area not directly heated (such as stores, covered parking areas).

Nett lettable area (NLA) is the gross internal area less common lettable areas and ancillary spaces that maybe directly heated or cooled such as elevator lobbies and corridors.

*Shaded area in table are parameters used in construction of the base case in this study.

Using these specifications, within the square floor plan of a 30m*30 m floor plate 14m*14m core area would be deduced as a non air conditioned zone. Ceiling height is 2.7m, with a suspending ceiling plenum of 0.8 m. The base case comprises a single un-insulated exterior 220 mm brick wall, and 40% glazing to wall ratio (WWR) of clear 6 mm clear float glazing. The inner depth of each façade zone is 8m from the façade.

6.2.1.4 Number of floors

Base case models have been found to vary in the number of floors per model. Sahu and Prakash (1979) concluded that the larger the number of floors and the greater the perimeter dimensions, the smaller the value of Surface area/ Floor area, hence less heat gain. The authors recommended a minimum of 7 storey high buildings for minimal heat gains from the façade and roof. However, different building heights for the conceptual models are found in literature, (Lam 2000) and (Chow and Chan 1995) based on existing office building survey built the conceptual model 20 storey high.

In the context of the thesis, the conceptual base case was chosen 7 storeys high which also coincide with a large number of office building heights in the city centre of Cairo. The number of floors of the base case model becomes a critical variable when the whole building energy consumption is under evaluation. (Wang et al. 1999) recommended isolating the other building envelope variables such as the roof and ground floors from façade thermal assessments by choosing an occupied space in the model that was situated in the middle of a three storey high model. The façade structure and the occupied zone examined were on the fourth floor (middle of a seven storey high model) of the base case. Hence the indoor zone on each orientation received minimal external thermal influence from the roof 's thermal transmittance and ground reflections. This way the impact on the cooling load from the façade would be examined in isolation from other building envelope variables.

In this study as the parametric comparison of results is based on a typical per m^2 energy consumption, this variable is of less importance. To minimize atypical simulation results from the ground floor level due to ground reflections and from roof level elevated indoor temperatures. Simulation results for an intermediate building floor are used as representative of the per meter square consumption of the building.

In conclusion the base case characteristics are summarized in (Table 3):

Table 3: Base Case morphology and façade configuration	
Level of model abstraction	Level A
Floor plate aspect ratio	1:1 (square)= 30m*30m
Percentage of non-air conditioning/air conditioning	20%
Number of floors	7
Façade configuration	
Window to wall ratio	40% Clear glazing 6mm thick
Opaque walls	No insulation on 22cm red brick walls.

6.3 Test variables (Dependant and Independent variables)

Nachmias (1992:54) identifies variables as an empirical concept; he states this relation as: *'Research problems are conveyed with a set of concepts. Concepts are abstractions representing empirical phenomena. In order to move from the conceptual to the empirical level, concepts are converted into variables. It is as variables that our concepts will eventually appear in hypothesis to be tested.'*

The description of the prototypical model depends on three aspects that are progressively difficult to describe.

a) The physical characteristics (such as window to wall ratios, façade layers and shading systems, number of floors and plan area).These physical characteristics are static, observable and relatively easy to record.

b) Building occupation patterns are the hard to define as it depends on actual area allocated to occupants, their patterns of occupying the space, their need for electrical lighting and zoning within a building.

c) The HVAC systems are hardest to define. Although the basic system configuration types were surveyed for the sample buildings there actual utilization of electricity was difficult to quantify since these systems are affected by their control, operation, efficiency and maintenance. The link between using air-conditioning systems for occupied and un-occupied spaces is almost impossible to define. Therefore engineering judgment is needed to assess these variables for the prototypical building.

This section identifies the test variables, grouped into dependent and independent variables. The dependent variables will be used to measure changes in energy consumption. The dependant variable is the building façade, looking at changing existing façade configurations whether these alterations are on single or double skin.

6.3.1 Dependant Variables

The dependant variables controlled for simulation are the building's operational profile and the climate profile. The operational profile within the simulations is based on optimum recommendations by design guides. The weather in any given location is variable. Relating climate parameters to electricity consumption at regional scales is dominant in literature. Results of these studies indicate various sensitivities of electricity consumption to local weather. Due to the peculiarity of this variable, results of simulation are only generalizable to similar weather conditions (Akbari et al. 1994; Sailor 2001).

6.3.1.1 Operational profile

In this investigation the specification of the plant system is idealized and purely conceptual as the room processes are the only concern. In this case cooling supply and heating removal is completely from the air within the indoor boundaries of a construction. The 'ideal' plant performance means that it controls the indoor temperature with no system inertia or time dependant characteristics (such as delays in startup, or time needed by the system to provide the control system).

6.3.1.1.1 Thermal comfort

Thermal comfort is the main objective behind using air-conditioning systems in Cairo. Chapter two has discussed issues underpinning the range of thermal comfort temperatures that are controlled within the office environment to provide thermal comfort to occupants, aiming to increase productivity. These variables were set using acknowledged standards (CIBSE, 1999)

- Outdoor air supply rates for sedentary occupants is 8 $L.S^{-1}$ $person^{-1}$.
- Summer dry resultant temperature (operative temperature) in office buildings general spaces/ open plans should be between 22-24 C^0 (± 1.5).
- Humidity levels are controlled between 30-60%.
- Infiltration is calculated at 0.5 ac/hr. Recent air tightness levels were shown to achieve 0.25 ac/hr. Due to the age of office stock in Cairo and from experience with workmanship levels the higher value was used in simulations.

6.3.1.1.2 Occupancy

It was observed that in Cairo there are different occupancy schedules. The universal pattern of 9a.m.-5 p.m. is generally found in office buildings including those used by the government, however a minority was found to work between 8 a.m.- 4 p.m. and in offices that were situated in change of use apartments it is generally found that these were occupied between 5p.m.-10 p.m. as these were used for afternoon medical clinics, private accounting services and lawyers, or engineering offices. The area that is allocated per person differed according to the type of organization work. Occupation patterns of buildings and the related use of computers and office machinery have a major influence on the thermal balance of a building. A portion of the internal heat load may be reduced by optimizing the work pattern in relation to the weather. This may be achieved by adopting earlier working hours in summer, and the use of energy efficient office machinery such as energy-saving computers and lower heat emission computer display screens. Traditionally the working day in Egypt started from 7.30 a.m.-2.30 p.m., but this has changed due to adoption of the international working hours system which coincides with peak day temperatures and solar radiation.

In this study the universal occupancy pattern from 9am-5p.m. is assumed. Occupancy sensible gains are at 90 W/person, and one person occupies 10 m^2.

6.3.1.1.3 Lighting and office equipment

Sensible gains from computers were traditionally calculated at 40W/ m^2. Traditional assumptions for lighting were 30- 20 W/ m^2 (Meckler, 1992)· Due to advancements in manufacturing lighting products and current energy saving programs and voluntary codes specifying energy saving electronic ballasts, and lamps as recommended by (ASHRAE, 1999) a 16 W/m^2 and lighting maintained luminance levels of 500Lux were assumed for lighting electricity consumption. Fluorescent lighting fixtures utilize 100% of the installed power during office hours and 5% in non-office hours.

New computers and office machinery are designed to comply with worldwide energy saving measures. As the life cycle of computers is short, it was assumed that during refurbishment, computers and office machinery are the first to be changed. For Office machinery sensible gains of 15 W/ m^2 were assumed.

6.3.1.2 Weather profile

An averaged over a period of 28 years between (1971-1999) weather profile was provided by the Metrological Center in Cairo. The weather profile included maximum and minimum monthly dry and wet bulb temperatures, air speed, and atmospheric pressure.

The original intention was to use an hourly weather profile provided by the Egyptian Metrology Agency. But as a large sum of money was requested equivalent to (15,000£), other options for finding a dependable source of hourly data were sought.

The profile used for these simulations is an hourly weather profile of Cairo generated by the software Meteonorm 4.0. The software generated wet and dry bulb hourly temperatures (Figure 9), cloud cover, wind speed, solar direct and diffuse radiation, and atmospheric pressure over a hypothetical year. Cloud cover and sunshine hours were also predicted by the software. Meteonorm 4.0 was also used to generate an average by month weather profile.

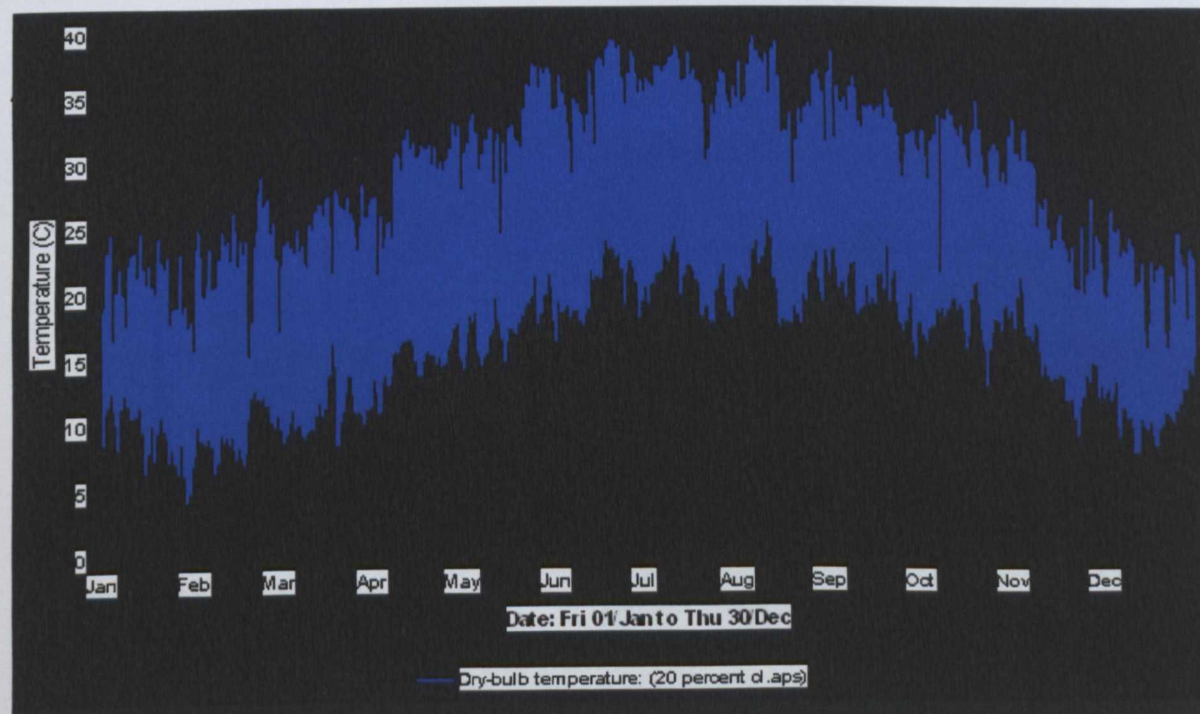


Figure 9: Ambient Dry Bulb Hourly profile

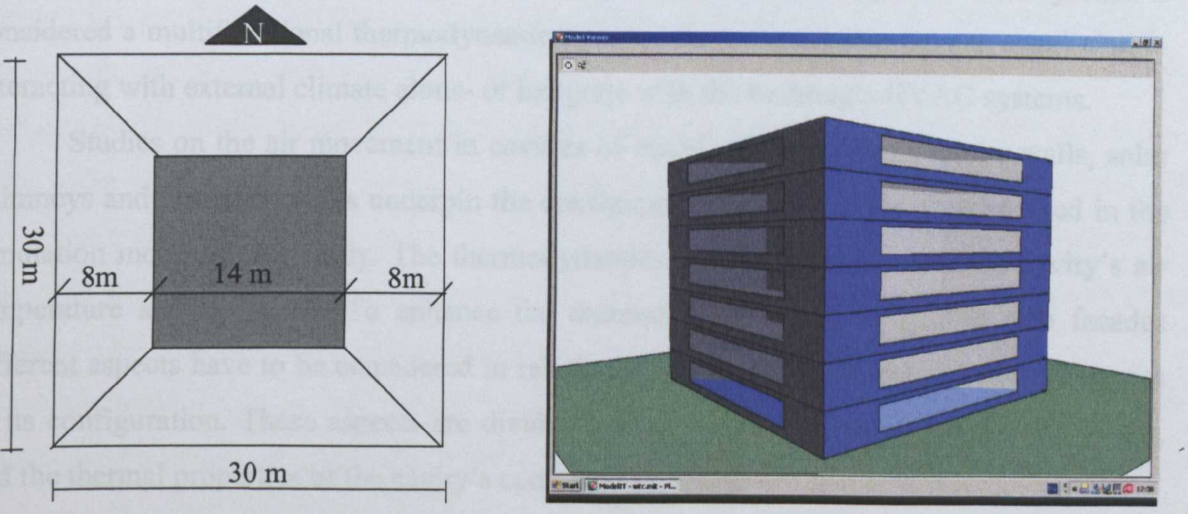
For validation of Meteonorm results, the average temperatures calculated over a 28-year period (1971-1999) from an urban location in Cairo was used to compare averages predicted by the software. Minor and insignificant variations between 0.3 °C -0.5 °C were found between the two sets of data and therefore the Metoenorm predictions were seen as viable for use in simulations.

6.3.2 Independent Variables:

In this study there are two sets of independent variables. The single skin independent variables and the double skin independent variables. Results from both sets are used to compare performance of thermally improved single skin facades to double skin refurbishment scenarios.

6.3.2.1 Single Skin façade configurations:

A 40% WWR is used for the base case façade configuration (Figure 10). However, as explained earlier in this chapter that the survey indicated a wider variety of WWR ranging between 20-60%.



Typical Floor Plan Isometric

Figure 10: Single skin plan and isometric configurations

Research on hot seasons in moderate climate and in hot arid climate has constantly advocated for the use of smaller WWR to decrease cooling loads. This assumption is investigated by changing the optical and thermal properties of glazing on different WWR, and by changing the thermal properties of the wall by using insulation.

Table 4: Glazing properties simulated for the single skin facade

Exterior Leaf Glazing Type	U-value W.h/m^2	Solar Coefficient (SC)	VLT	Thickness
Clear Glazing	5.6	0.96	0.89	6mm
Double clear glazing	2.8	0.8	0.76	6+12+6mm
Body Tinted	5.6	0.8	0.61	6mm
Reflective glazing	5.6	0.6	0.44	6mm
Double reflective glazing	2.8	0.5	0.3	6+12+6mm
Triple reflective glazing	1.8	Hypothetical		6+12+6+12+6mm

6.3.2.2 Double skin façade configuration:

The thermal performance of double skin facades may be related to other types of passive cooling systems in buildings, such as the solar chimney, a Trombe wall, and breathing wall systems where the exterior layer of the façade is covered with other materials such as marble or bricks. Double skin facades similar to the previously mentioned systems is considered a multifunctional thermodynamic system where the air channel can stand alone - interacting with external climate alone- or integrate with the building's HVAC systems.

Studies on the air movement in cavities of double skin facades, Trombe walls, solar chimneys and breathing walls underpin the configuration of double skin facades used in the simulation model in this study. The thermodynamics of the cavity is related to cavity's air temperature and air speed. To enhance the thermal performance of double skin facades different aspects have to be considered in relation to the climatic context and the economics of its configuration. These aspects are divided into air flow rates, cavity height and width, and the thermal properties of the cavity's construction layers.

6.3.2.2.1 Air flow rates:

The difference between the ambient air temperature and the higher cavity temperatures drives the air upwards by buoyancy. The larger the difference between the cavity and ambient temperature the faster the air flow rates (Oesterle et al. 2001).

Depending on the solar radiation angle of incidence and optical properties of glazing used, the presence of an exterior glazed surface increases penetration of solar radiation into the cavity. (Tenhunen et al. 2001) monitored a double skin façade of 7 storey height building in Helsinki between 24/2-2/3 2001 and reported elevated cavity temperatures on the 7th floor, higher by 17°C during solar incident hours.

This in turn increases cavity air temperature and inner wall surface temperatures. In a hot arid context, the mass flow rate was found to increase with increasing surface temperature. When compared to a built up wind tower with no glazing surfaces, solar chimneys have higher mass flow rates even in conditions of lower ambient wind speed (Bouchair 1994). (Afonso and Oliveira 2000), tested the difference in air flow rates between a 2m high solar chimney and a conventional chimney in Porto (Portugal) using a constant emission tracer gas techniques. The study reported that even in low solar radiation incident on the glazing surface (250 W/m^2) in the solar assisted chimney the air change rate is increased by 30% when compared to an all solid conventional chimney. The air flow rates daily amplitude followed the variation in daily incident solar radiation, with air flow rates reported to be higher during sunshine hours. The direction of the air stream is also affected by the amount of incident solar radiation. (Balocco 2002) studied a ventilated façade where the outer layer of the façade is covered by granite, and the height of the chimney was 6 and 14m. The study controlled cavity height while varying the width from 7-35 cm. Results reported increased air flow rates within the cavity in a linear relationship to increasing incident solar radiation. The air stream moved from bottom to top whenever there was solar radiation but inversion of the air stream was expected during night time hours.
From the previous, it is evident that the glazing surface leads to elevated temperatures in the cavity which in turn enhance natural buoyancy.

In cases where air speed is predicted to be insufficient to assist natural buoyancy, active mechanical systems have been used to increase air flow and therefore reduce cavity temperatures and conduction through internal facades. Executed examples include the Union

Chiminique Belge (UCB) in Brussels (Kragh 2001) and Swiss RE Headquarters in London (Kitson 2003).

In the simulations the air speed is variable and linked to the dynamic weather profile.

6.3.2.2.2 Cavity height:

The effect of cavity height has been studied by experimental work and monitored on small scale facilities with a maximum height of 3m on solar chimneys. These studies give an insight on the performance of the double skin cavities but results could not be compared to predictions of air movements in double skin façade due to increased aspect ratio between cavity width and height in double skin facades in comparison to those reported in test cells. (Afonso and Oliveira 2000) varied by simulation the solar chimney height from 0.5 to 3 m with a constant chimney cross-sectional area. The results indicated an increase of approximately 65% in air flow rates between the 0.5-3 m heights.

(Oesterle et al. 2001) studied the relation between the thermal uplift in a double skin façade in relation to excess temperatures and cavity height. The study concluded that increasing the cavity height between 2-7m increases the buoyancy effect, and has a linear relationship between increased cavity temperatures and height of air flow.

A limited sensitivity test was carried out by varying the cavity height on the West Façade to study its effect on cooling loads in adjacent rooms to a transparent double skin façade configuration. The Cavity was increased from a one storey height to full building height with a constant air change rate of 3 ac/h is assumed.

Simulation results using APACHE, are presented in Table 5: Sensitivity of model to cavity height indicating that the total room cooling loads were indirectly proportional to the cavity height, i.e. the more the cavity increased in height the less total cooling loads were predicted in the West Oriented room. Compared with a full model height double skin façade the one storey height double skin façade increased the total cooling loads of the West Oriented room by 12%. This may be attributed to the increase in conduction gains, the slower movement of air due to lower temperature differences between air inlets and outlets

Table 5: Sensitivity of model to cavity height

Cavity height	Annual total cooling load on West façade/typical m^2	% Increase
3.5 m	1604	12%
7 m	1524	8%
10.5m	1458	3%
17.5 m	1429	0.8%
21 m	1417	0%

In this investigation, the double skin façade is the full height of the façade. This height is fixed throughout the simulations. Temperatures are expected to rise within the cavity thus aiding the thermal buoyancy in the façade to move air in an uninterrupted flow to the outside of the cavity. The full height of the façade is also in response to economic considerations explained later in this section.

6.3.2.2.3 Chimney cross-sectional area:

(Afonso and Oliveira 2000) reported a linear relation between the increases in air flow rates as the chimney cross section increased from 1-5 m. The study concluded that the increases in chimney width increase the amount of heated air thus favoring higher air flow rates. However, the previous study examined higher than found in literature cavity widths between the two facades (7-150 cm). Wang *etal*, (1999), through simulation studies varied the depth of the cavity from 0.5-1m, results demonstrated that the narrower cavity 0.5m indicated a minor increase in cavity air temperature 2C^0 during a summer mid day which did not indicate any major effects on increasing cooling loads. However, the study warned that the apparent benefit of decreasing cavity width to encourage solar penetration in winter in moderate climates is offset by an increase in heat losses to the cavity. Balocco (2002) results indicated that varying the channel width wider than 7 cm induced an almost stable reduction in conduction loads from cavity to indoors.

(Sparrow and Azevedo 1985) studied the effect of channel width on natural convection experimentally between two vertical plates. The study concluded that heat transfer was reduced to the indoors if the width of the cavity was equal to the interior boundary layer thickness.

From the previous research results it is concluded that unless the cavity width is decreased substantially, less than 7 cm, it has a minor effect on indoor thermal comfort. The depth of the cavity is important to encourage air flow in the cavity. The previous reviewed research indicates that increasing the cavity width attributes to decreasing frictional resistances to the air flow, while maintaining the benefit of natural buoyancy in the cavity. The inside boundary layer to the cavity is found to warm up but without increasing significantly the indoor air temperatures. The mass flow rate was found to increase with increasing cavity surfaces temperatures. It is concluded that in a hot arid climate the increase in channel width is beneficial to enhance the thermal performance of the double skin façade.

In the simulations the width of the cavity was controlled at 1 m. The rationale behind this choice is further explained in 5.6.2.2.6 later in this chapter.

6.3.2.2.4 Cavity construction layers

The construction layers of a double skin façade are based on curtain walling construction methods. However, preliminary research in Nordic countries (Tenhunen et al. 2001) has indicated there are variations in the structural performance of the exterior layer when aluminum, stainless steel or hot dip galvanized steel is used. The use of Aluminum is assessed as light weight and easy to work accurately but the co-coefficients of thermal expansion and thermal conductivity are high and have a lower fire resistance when compared to galvanized steel and stainless steel. Stainless steel is the preferred metal for the exterior façade construction for its long life, easy maintenance and good fire resistance. However the cost of the material is still prohibitive in developing countries.

Studies in cold and moderate climate are based on the logic of increasing the insulation of each construction element of the double skin façade and methods to increase cavity air temperatures then predicting how this affects the overall thermal performance. To increase air temperatures in the cavity air inlets and outlets are closed. This provides a surrounding warm and stagnant air cushion to the building thus decreasing the extreme cold winter heating requirements. The general variations found in research indicate a clear glazing on the outer skin while varying glazing properties and layers on windows of the interior layer. (Tenhunen et al. 2001) through a survey on constructed office buildings in Finland concluded that the outer layer of the double skin is fully glazed with clear glazing while all variations were found on the window glazing of the interior facade. Insulating glazing units are used for windows with multiple layers of glazing up to triple layered heat insulating glass units. However, the insulating glass units of windows have an outermost layer of coated low-e glass to reflect heat gain back into the room while excessive solar gain to the cavity. Solar control glass and electrically heated glass are also used for windows. Body tinted glass is not used for window glazing, as free of iron oxide glazing is found to increase natural light and reduce the greenish tint appearance of the glass rich in iron oxides. This increase of window layers was examined and its thermal performance was challenged (Fiast 1998; Oesterle et al. 2001). Both studies compares increasing window glazing layers with a closed and continuously opened cavity. Results indicated that closing the cavity and trapping heated air reduces the U_w considerably. Opened cavities in winter slightly improved the U_w . (Oesterle et al. 2001) argued that decreasing heat transfer to this extent would increase the danger of condensation on the window's outer pane. In warm summer temperatures, increasing the glazing layers on windows of the interior wall to double clear glazing, did not offer major reductions in cooling loads (Wang *etal*, 1999), 5% reductions was predicted compared to a single clear glazing on windows (Hamza, et al 2001b). It is concluded from the previous studies that increasing glazing layers on windows may slightly improve conduction through glazing to the indoor environment, but the air movement inside the cavity is the dominant factor on the thermal performance of double skin facades. Closing the cavity to the prevent exhaustion of heated air is logically not suitable for a hot arid climate.

Increasing the glazing layers on the outer layer of the double skin façade was studied in the UK climate. Increasing the glazing layers on the exterior façade does not seem to significantly benefit the annual energy savings, as increasing the double skin outer layer to double glazing slightly increased the cavity's temperatures in winter thus reducing heat loss and heating energy. But in summer higher temperatures were predicted in the cavity and therefore increased cooling loads by 30% (Wang *et al*, 1999).

Studies looking at the benefit of insulating opaque areas on the inner façade of a double skin configurations reported its effect on mass flow rate in the cavity and on indoor gains. (Afonso and Oliveira 2000) reported that it is fundamental to use thermal insulation on the brick walls inside the cavity to increase the solar assistance efficiency in warming up the air in the cavity instead of warming up the inner walls, to increase air flow rates. The study reported a 5 cm insulation thickness as ideal, if insulation is not used solar assistance is reduced by 60%.

Ambient air temperatures in Cairo in summer are well above comfort temperatures. As the cavity temperatures are constantly above ambient due to incident and reflected solar radiation, using natural ventilation from cavity to indoors during peak solar incidence hours in summer is not recommended.

6.3.2.2.5 Economics of Double skin Façade construction:

Features of an economical double skin façade illustrated by (Oesterle, et al 2001: 185) are taken into consideration:

- Avoidance of opening elements operated by electric motors;
- The outer façade should contain non-closable openings which in the context of the study is the whole inlet and outlet areas.
- The floor of the intermediate space should not be accessible, or only for cleaning purposes
- A minimum number of constructional types should be used.
- Although the authors recommend that intermediate façade space should not be too deep, between 30-50 cm, this particular criteria is not used within the context of this investigation, as it poses difficulties in cleaning, maintenance and replacement of the façade elements within the specific climatic constraints of Cairo.

6.3.2.2.6 Double skin façade configuration and glazing properties used:

The width and height of the cavity are controlled variables. To increase the flow rate and decrease frictional forces a width of 1m is chosen. The decision to place the proposed double skin façade construction 1m away from the single skin façade is based on the feasibility for maintenance and cleaning. As explained in the context chapter that Cairo has a high level of air pollution coupled with sand storms, these are constraints that may not be disregarded in any façade construction. The thermal and optical properties of the outside glazing layer are independent variables to study their effect on indoor cooling loads. Figure 3, indicates the typical floor plan of the 7 storey high simulated office building, with the double skin façade placed 1m apart (Figure 11).

As literature review indicated that the use of Aluminum is not recommended, while the use of stainless steel is expensive, a planar glazing system is chosen for the simulation. Planar systems are frameless and are fixed to the interior façade. Pilkington recommends a 1 cm thickness glass to be used.

Three types of thermal and optical properties were simulated for the exterior layer of the double skin façade (Table 6):
Clear glazing.
Body Tinted
Solar Reflective glazing.

Table 6: Properties of Glazing used for the outer leaf of the double skin facade

Exterior Leaf Glazing Type	U-value W.h/m^2	Solar Coefficient (SC)	Thickness in mm
Clear Glazing	5.6	0.89	1 cm
Body Tinted	5.6	0.59	1cm
Reflective Glazing	5.6	0.27	1cm

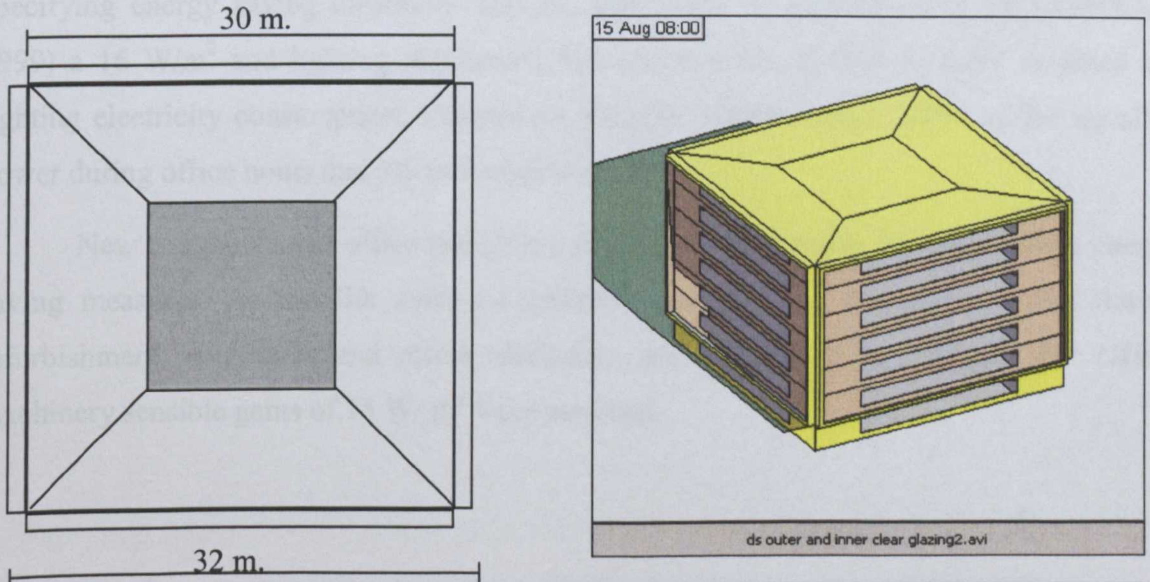


Figure 11: Typical floor plan and isometric for the Double Skin Façade model

6.4 Methods for examining the performance of double skin facades:

To choose a suitable methodology to investigate the research hypothesis a suitable measuring method to quantify the impact of the different façade refurbishment configuration on the cooling demand is identified. A methods literature review was carried out. A 'methods literature review' (Cooper 1989) in this context is defined as a literature review focusing on methods and definitions used in previous research and obtained from both primary (articles) and secondary sources (books) and restricted to studies pertinent to the specific issue of double skin façade thermal performance . These reviews provide summaries of previous studies with an actual critique of the strengths and weaknesses of the method used to examine the topic under study.

From literature reviewed, four different methods to study the thermal performance of facades prevailed. It is prudent to mention that these methods are generally used to study the thermal performances of all different façade configurations, in the context of this study, emphasis are on methods used to predict and assess the thermal performance of double skin façade.

The four methods are:

- Mathematical modeling (Tedorovic and Cvjetkovic 2001)
- Experimental work in test facilities (Saelens, D. (2002), and Jones *et al* 2000). Wind tunnel experiments to study buoyancy in cavity and natural ventilation possibilities.
- Monitoring of parts of existing double skin facades is a category of this method (Oestrich et al 2001).
- Building energy simulation packages (Afifi, 1994), (Wang et al. 1999) and (Hamza et al, 2001a)

All methods were found to have their place. Although every method has its implicit limitations, these limitations have not created a definite reason for rejecting any of the previous methods in research.

The scope and limitation of each method will be discussed and the rational behind choosing building thermal simulation for this study is explained. These methods are reviewed in this section to understand their scope. Reported results in previous literature, obtained by using these different methods are used to analyze and create the matrix of double skin façade independent and dependant variables that are pertinent to simulate to achieve the aim of the thesis.

6.4.1 Mathematical Modeling

Traditionally, designers relied on disparate calculation methods for heat transfer in buildings and internal load calculations. . (Tedorovic and Cvjetkovic 2001)proposed a mathematical model to study heat transfer in double skin facades. As flow paths of energy in a building are complicated, manual methods were recognized as tedious and time consuming resulting in weak coupling between the various calculation steps. For studying double skin facades, equations were used for creating simplified computerized energy software by inserting the simplified mathematical equations to MATLAB software (Maio and Paassen 2001) , these mathematical models are calculations based upon a piecemeal approach, leading to simplifying the dynamic effects of heat transfer in buildings into a steady state condition. However, CIBSE (1998:p.29) recommends that manual simplified calculations be used to roughly assess outcomes from energy simulation softwares.

6.4.2 Experimental Work

Reported experimental work on double skin facades has mainly focused on one or two specific aspects of the performance of double skin facades. (Fiast 1998) used a full scale mock up to study convective heat transfer coefficients in double skin facades. (Ziller 1999) used tracer gas and wind tunnel experiments to study different scenarios of natural ventilation for office buildings with double skin facades. (Jones et al. 2000)presented initial results from a full scale model of the Commerzbank double skin façade used to study the performance of the cavity during the cooling season. Saelens, D. (2002) used a double façade test cell in the Katholieke Universteit Leuven in Belgium to compare the thermal performance of double skin facades to Air flow windows (where air freely, or mechanically moves between two panes of glass).(Chiu and Shao 2001) studied the effect of varying the cavity width on possible savings on heating energy on a test rig and results were used to validate a CFD simulation.(Spinner et al. 2002) use a one storey height double skin façade test facilities in the University of Munich, Solar research Center. The test facility is used to test the possibility of integrating passive solar systems to preheat air entering the cavity to be used for natural ventilation in office spaces. However most of the previous mentioned research focused on temperate and cold climates.

Experimental methods in studying double skin facades depend on the availability of specialized test cells, and data logging systems to log measured parameters on a computer system. Results can give actual and nearer to reality understanding of the dynamic performances of a façade's configuration.

However inherent limitations could not be ignored. Testing the effect of changing one independent variable is time consuming and expensive, such as changing the glazing type or window to wall ratio. The expenses of running tests are generally high and are funded by major international projects. To study the thermal performance of double skin façade configurations in this case, the test cell had to be built in the specific climate or in a similar arid climate where the performance of double skin façade is to be tested. No such facility was found at the time of this study. Although Cairo has building test facilities in the Building Research Institute, these facilities are not constructed to test sophisticated types of façade configurations. A further limitation to this method is that the dynamic dependant variables affecting internal gains are normally excluded (such as occupancy and utilization of lighting and office equipment), which excludes many dynamic interactions between the building and its envelope which primarily affect the prediction of energy consumption in buildings. Due to the limitations of the different types of resources needed for this method it is not used to answer research hypothesis.

6.4.3 Monitoring.

The construction of double skin façade has gained popularity in Europe during the 1990's. The published literature on monitoring of existing buildings is scarce and in its preliminary form. (Tenhunen et al. 2000) monitored a full height flue double skin façade construction in Helsinki composed of seven floors to study temperature fluctuations within the cavity. The measurements were taken from the South façade on the 7th and 3rd floor during February/March 2001. (Oesterle et al. 2001) monitored the 'City Gate Building" in Dusseldorf to study the effect of wind speed on wind movement inside the corridor double skin of the building. Measurements were carried on the 16th floor on the west façade and recorded during the August 1998 for a sunny/ windless day and sunny/windy day.

As evident from the above monitored buildings that again only one aspect is monitored and for a short duration of time due to the high expenses involved. Monitored data is a key source of information and is used to validate both experimental and simulation work outputs. But currently no double façade configuration has yet been constructed in Cairo. Some modifications of the Double Skin façade concept have been constructed in Southern USA. Arizona library protected the whole interior by adding the service areas on the Western and Eastern Facades thus creating an unglazed buffer zone (known as the saddle bag) between external and internal environments (Baird, 2001). However the concept of Double Skin facades in utilized as these facades are not used for views out, and no air flow is utilized to remove excessive conduction gains in the cavity.

However other forms of passive heating and cooling systems integrated into facades' thermal performance have been examined in moderate climates on nearer to hot climate profiles. Although not double skin facades but part of the thermal performance of these systems may be used by synthesis to determine aspects of the thermal performance of double skin façades, such as studies on sunspaces in hot days in Athens (Mihalakaou 2002)

Double skin facades are still a relatively young technology; their construction is more or less new ground for everyone in the building sector. Monitoring of 1:1 Model facades plays a crucial role in determining the aerophysics and control of active components of the façade and their interaction with internal air conditioning systems. Prior to the release of the design of serial production model facades would allow all construction parties to jointly check and validate the proposed façade construction and its performance, and optimize the goals that needs to be achieved. (Oesterle *et al*, 2001)

6.4.4 Simulation

The increase in complexity in design and performance evaluation of different design alternatives necessitates utilization of simulation tools. Augenbroe (2002) describes using simulation models as a 'creation' of a behavioral model of a building in a given stage of its development whether reflecting it as designed, or as built or as operated specifications. The model is developed to reduce real life physical entities and phenomena to an idealized form with a desired level of abstraction.

Building energy simulation models range in sophistication from simplified (steady state heat transfer) to fully comprehensive softwares (dynamic heat transfer models).. Simplified software models are sufficient to predict building overall energy consumption and peak cooling or heating loads. In simplified softwares, heat transfer models are built upon simplified assumptions underlying the thermal network or approximation of some energy mass flow path or their complete omission.

The need to use sophisticated and detailed hourly dynamic software arises when temporal changes of ventilation or internal gains, climatic variations are to be considered to predict hourly variations in building energy consumption. However, even in comprehensive and dynamic simulation tools, the basic rational behind the model construction (modeling) is to selectively reduce the complexity of the related energy systems in an attempt to lessen the computational load and the corresponding input burden placed on the user.

Limitations of this method are that simulation packages are critical to use for evaluation of energy usage in buildings as these softwares are generally criticized as adhering to a tool-box metaphor which requires the designer to recognize a task, locate a suitable program, apply it and translate the output to appropriate modifications to the design hypothesis (Clark 2001).The software tool as a closed code (black box) causes a level of uncertainty in data outputs requiring validation of results. Therefore the results of simulations should not be used as a free of error or accurately representing the reality of thermal transfer or energy used in buildings. The results of these simulations are used as a predictive tool to support conscious energy design decisions. The main advantage of this approach is the versatility and flexibility in simulating different room boundary conditions, building shape and orientation alternatives (while accounting for variable occupancy, lighting and weather profiles) in a shorter time compared too other methods such as in experimental or field monitoring work. While the main disadvantage of this system is that only the room thermal processes are examined, while all other processes of plant cooling or heating generation, distribution losses and control are assumed to be idealized. Subsequently only gross energy requirements are predicted, while fuel consumption or energy required for system components, and fluid distribution are not accounted for.

6.4.4.1 Evolution of simulation software:

The evolution of simulation tools from simplified manual mathematical models to complex and dynamic modeling approaches passed through four major stages (Clark, 2001).

The first simulation generation was based on handbook oriented mathematical models that were easy to use but embodied many simplified assumptions. These simulation tools had no significant attempt to faithfully represent energy and mass flow that occur in real buildings.

The second generation emerged in the mid 1970s and stressed on complicated building dynamics but was still based on standard theories and therefore was still considered a piecemeal approach with limited application. The temporal aspects of heat transfer were considered especially in multi layered constructions but still HVAC system modeling was confined to the steady state.

The third generation emerged in the mid 1980's aided by advents in personal computers. This development signaled simulation softwares depending on numerical methods that assume that only time and space are independent variables; while all other systems are dependant i.e. all system parameters are dependent and no energy transfer process is solved in isolation.

The forth generation materialized in the mid 1990's with more integrated and dynamic modeling in an attempt to emulate a good match with reality. Integrative data modeling is to process the energy flow path simultaneously while treating the building and its systems as an entire integrated systemic whole. Dynamic modeling considers the flow of energy as non-linear so each parameter depends on the thermo-dynamic state and a complex intra/inter part interactions. This was achieved depending on an intelligent knowledge base. This resulted in easier to use software packages, predictive and multi variant data outcomes that are interpretable. A forth generation software was used as a tool in this thesis. APACHE is a multi node system built on an integrative environment modeling system. The dynamic simulation attempts to simultaneously link the different building nodes as independent variables. Each network node consists of various dynamic interactions between the building elements, operational profiles, and internal loads generated. Each node has a variable state and different capacitance: each node responds at a different rate as it competes with its neighbors to capture, store and release energy. The number of nodes that are created determines the resolution of the software used.

Dynamic simulation tools are based on two modeling techniques. The first is the response function modeling which is widely accepted in North American software packages. The second is numerical approaches. In the context of design tools intended to provide an early indication of performance trends both approaches are equally appropriate and can handle dynamic interactions occurring within buildings. Clarke (2001) however recommends softwares based on the numerical methods if a closer emulation for reality is required. The Response function method is a mathematically logical technique and the outcome of many years of research and development. However it is a technique that emerged in response to the need to introduce dynamic heat flow and interactions between different building nodes into manual static calculation methods. Outputs from response function models are easily validated by using existing scientific theories in comparison outputs from numerical models.

Numerical methods software packages (such as APACHE, and TAS) evolved as the result of the spectacular increase in computational capabilities. This method allows significant integration between the building energy systems, such as interactions between building fabric, HVAC psychometric processes, control electrical power use and occupants. Clarke (2001) describes the construction of these dynamic softwares as a three stage process: system discretisation followed by establishment of a nodal equation set, which is then solved simultaneously to obtain the distribution of the state variables. For example: for the analysis of the heat and inter-zone air flow within a ten zone building, such a model might typically comprise 3500 equations and substantially more where intra zone air movement is included. However these systems although complex in nature are based on approximation of partial differential equations that govern heat flow between systems such as the Fourier heat equation applied to measure conduction, or the Navier-Stokes momentum equation related to fluid flow. In conclusion although complicated in nature numerical models are continuously under development to reach a reliable simulation to energy performances of buildings in real life situation.

The previous calculations methods have been used to formulate a variety of thermal modeling software (Table 7) lists the most commonly used softwares for research purposes by their country of origin.

Table 7: List of commonly used thermal modelling software in research

Simulation software	Country of Origin
APACHE	UK
TAS	UK
ESP	UK
ESP-r	UK
ESP+	UK
HTB2	UK
SERI-RES	UK
DEROB	USA
DOE	USA
Enerwin	USA
EnergyPlus	USA
Energy2	USA
BLAST	USA
TRNSYS	USA
CalPAS	USA
CHEETAH	Australia
CLIM2000	France
TSB13	Demark
S3PAS	Spain
WG6TC	Italy

In conclusion, reviewing the previous methods no fundamentally 'correct' method for performing building energy consumption calculations was found. Buildings are subject to random driving forces and uncertainty in their parameters. It is therefore not possible to accurately predict every aspect of their performance by using any of the existing methods for assessing energy consumption in buildings. As the processes involved are highly complex and their exact representation is beyond the capability of manual mathematical modeling, current computing power used for simulation, as well as the number of data loggers and in-situ measurement tools that maybe used for monitoring work. Accepting the uncertainties in all methods as a limitation, building energy simulation was chosen as a viable prediction tool to simulate different variables underlying the performance of both single and double skin facades.

6.5 The Method of measurement using APACHE as a simulation tool:

The key reason for selecting building simulation over other methods used to predict energy utilization in buildings is that real-life systems are often difficult or complicated to analyze by simple manual mathematical models, experimental work or monitoring techniques. Currently the most powerful technique available for the analysis and design of complex systems (like buildings) is computer modeling and simulation (Hensen,1994). Modeling is the art of developing a model which faithfully represents a complex system. Simulation is the process of using the model to analyze and predict the behavior of the real system to emulate future reality (Hensen, 1994). Therefore building thermal simulation aims to carefully extract from the real system, the elements relevant to the stated requirements and ignoring the relatively insignificant elements.

APACHE (Applications Program for Air-Conditioning and Heating Engineers) is a comprehensive program for analyzing the thermal performance and energy use of buildings. The data required for **APACHE** is derived from a 3D data model, which can be generated from 2D DXF drafting modules or from the **APACHE** system's own 3D data model creation tool called **ModelIT**. It enables the examination of the thermal properties of constructional elements, calculate heat gains and losses, calculate heating and cooling energy requirements, check for conformance with Building Regulations, and perform dynamic simulations of system and building operation (APACHE v 4.1 manual). The software confirming to CIBSE (GUIDE A, 1999) criteria for dynamic software includes representations of:

- Internal room surface heat balance
- Non-steady-state fabric conduction
- Internal solar distribution
- Temporal distribution of internal heat gains
- Temporal variations of the external climate
- External solar radiation

The software is also complaint with (ASHRAE 1999) requirements for a dynamic model in which the minimum ability to explicitly model the building envelope are the following:

- A minimum of 1400 hours per year
- Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points and HVAC system operation, defined separately for each day of the week and holidays
- Thermal mass effects
- Ten or more thermal zones

6.5.1 Data Input:

Data input starts by creating the databases that are managed through a graphical interface. Data bases (Figure 12) are related to construction materials, occupancy, internal gains, climate, air movement and systems. They are divided into three main interfaces.

- **APlocate**, which allows the user to modify standard weather (system database) and site location data. Geographic information of Cairo including latitude, altitude, and height from sea-level are found on the system library. However, all weather related data including the average values and the hourly weather data for Cairo were fed into APlocate.
- **APcdb**, allows the user to modify the standard constructions (system database) or create and edit a project specific construction database. **APcdb** permits the definition of a detailed layer-by-layer description of the elements that comprise a particular construction. The system library is comprehensive and updated. When user modified layers are introduced the CIBSE U-value and the ISO U-value are calculated. Calculations also include inside and outside surface

resistances, conductivity, thermal capacity and density Table 8) details data for glazed and opaque constructions calculated by APcdb

Two profiles were user modified.

1. The first is the un-insulated 22 cm brick walls.
2. The second is all planar glazing types used for double skin configurations, these were created using Pilkington Glass Manuals.

Table 8: Calculations performed by Apcdb	
For opaque surfaces	For glazed surfaces
summary of input data	summary of input data
surface resistances	surface resistances
thermal transmittance (U-value)	thermal transmittance (U-value)
admittance (Y-value)	directly transmitted component of solar radiation
decrement factor and time lag	inwardly retransmitted component of solar radiation
surface factor	

APpro, which allows the user to modify the standard profiles (system database) or create and edit a project specific profiles database. **APpro** is the profiles database manager for the **APACHE** system Profiles contain information on the time variation for each operating or occupancy patterns profile, and their shapes can be as complicated as required (using equations if suitable). Profiles may be absolute or percentage.

Computers and office equipment were assumed to be at 50% from 8-9 a.m. and 5-6 p.m., 100% operation between 9 a.m.-5p.m.and 10% for servers overnight

Lighting profiles were 50% from 8-9 a.m. and 5-6 p.m, 100% operation between 9 a.m.-5p.m.and 5% in non-office hours to account for security lights.

Occupancy profiles were 50% from 8-9 a.m. and 5-6 p.m, 90% operation between 9 a.m.-5p.m.and 0% in non-office hours.

The Geometrical model is entered using the model builder graphical interface facility (ModelIT) within the Virtual Environment. ModelIT, allows the user to graphically create a 3D-geometry model of the building and assign attributes from data bases (construction layers, operational profiles, and weather profiles) to this geometry.

Three subroutines may be run internally to calculate the sun shading effects between the building elements of the façade or shadows from neighboring constructions. The sun shading sub-routine **(SunCast)** is run for all simulations. SunCast, was not used to predict the effect of air pollution on the scatter of solar radiation

However the detailed sub routine of APACHE-Sim was used for all simulations but assuming an idealized HVAC system for simulation. The Air flow routine was used to link air flow in the cavity of the double skin façade to external wind velocities but no natural ventilation is assumed from cavity to rooms.

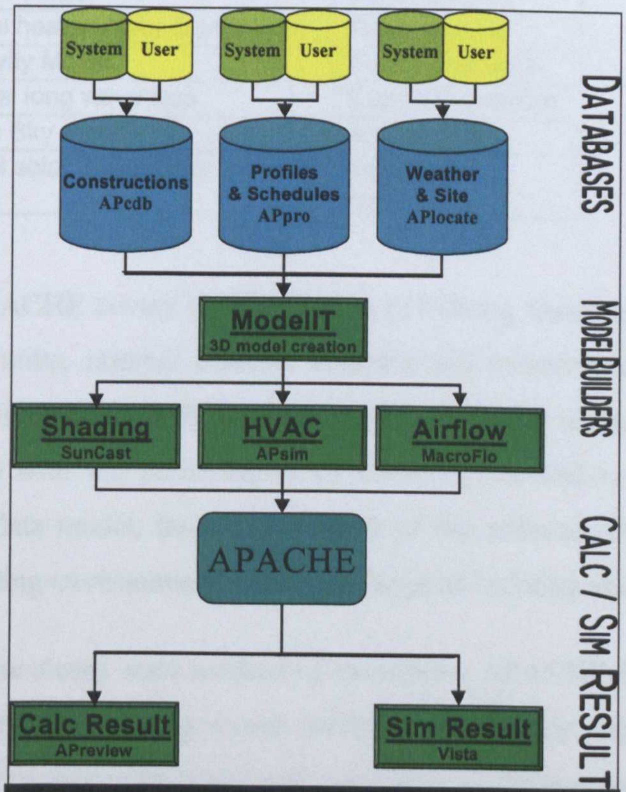


Figure 12: APACHE Data Model (APACHE Manual v4.1)

The basic concept of the **APACHE** system is to create project specific default data for site, constructions and profiles. Simulations can be performed for any number of days up to a whole year, allowing the prediction of the annual energy consumption of the HVAC systems in a building. The program also summates the annual electrical consumption for lighting and equipment from the schedules and levels of use that have been specified. The program uses finite difference techniques to model the transmission and storage of heat in the building fabric and simultaneously analyses the performance of the HVAC systems with user defined time steps as low as six minutes. The software is considered a dynamic calculation methods. It is important to understand that within the dynamic simulation method some variables are fixed to constant values (Table 9) illustrates explicitly modeled and static values of variables within APACHE-SIM

Table 9: APACHE-Sim Calculation method

Program Type	Commercial
Solution Method	Finite Difference
Window Model	Fixed U-value
Internal heat transfer Co-efficient	Fixed U-value
Air Cavity Model	Fixed resistance
External long wave loss	Explicitly modeled
Diffuse Sky model	Anisotropic
internal solar distribution	To various surfaces

In design mode, APACHE covers the calculation of heating, cooling and latent room loads, the sizing of room units, internal comfort analysis and codes/standards checks. In simulation mode, APACHE performs a dynamic thermal simulation using hourly weather data. Linked modules deal with the performance of HVAC plant and natural ventilation (Figure 12). Based on the data model, the main strength of the software is that it operates within an integrated computing environment covering a range of building analysis functions.

Its advantage over the steady state method of calculation APACHE-Calc is its ability to calculate direct solar radiation entering rooms behind a double skin façade. The steady state model treats all radiation transmitted through a window as diffuse energy completely absorbed by the room's surfaces. In single skin facades this assumption is defended in situations where estimation of cooling loads were used. The direct transmittance of direct solar radiation would be absorbed by the surfaces of the room behind the façade immediately (treated as a black body) and all other rooms behind this zone would be treated as internal zones where no direct solar radiation is reached. This simplification is unacceptable in cases where glazed spaces such as atriums or double skin facades are to be studied. These glazed spaces exhibit quite different characteristics in dealing with direct solar radiation varying with the properties of glazing used on their surfaces. While the proportion of transmitted radiation which is retained in a building with a single skin façade is about 95-100%, for a glazed space this proportion may vary between 30-85% according to the optical properties of the glazing used for these atriums of multiple layer facades (Wall 1997).

In a double skin façade construction, a proportion of the short-wave energy, arriving directly from the sun or diffusely after atmospheric scatter and terrain reflections eventually find its way through the external glazed façade construction into the subsequent glazed surfaces where it will contribute to the inside surface heat flux.

The component of the incident beam, which is transmitted, will eventually strike internal exposed surfaces and with no perceptible time lag will act in a similar manner to which it performed on the outer surface. To simulate double skin facades the software is required to have a sophisticated solar algorithm able to predict the penetration of direct solar radiation through the external construction to cause 'deep' construction heating in contained spaces of the building. In cases of completely transparent structures (such as double skin facades), the short-wave energy impinging on the outermost surface is partially reflected to the outside atmosphere, partially transmitted as direct solar radiation into subsequent spaces and partially absorbed by the glazing layer itself. APACHE incorporates an accurate solar modeling algorithm for predicting surface positions relative to the solar beam as well as exposed surface shading. Surface to solar position is a function of site latitude and longitude, metrological data expressing time of day and model surface geometry.

6.5.2 Data Output:

APACHE presents a wide range of outputs in tabular and graphical form. The forms of data output are numerous and need a data management system in order to be able to prepare results for excel analysis.

Data Outputs may be exported in a variety of common formats such as .txt and .rtf formats. This facilitates importing data into excel sheets for further analysis. However for a large number of simulations this is a time consuming method.

However, detailed thermal performance of the opaque fabric and the glazed areas can be assessed separately using the steady state thermal modelling too CIBSE Admittance Method for heat loss and gain or the Dynamic software APACHE-Sim. APACHE-Sim provides up to half hourly break down of results for climatic variables, room and system thermal responses.

6.6 Testing Reliability of Simulation as a Measurement Tool:

Computer simulations aim to represent complex real world building performances. Thermal processes across the building envelope are characterized by their nonlinear nature. Simulating these processes would require computing levels unavailable at the moment, a level of abstraction is imposed on the model leading to simplifications and approximations. Therefore absolute accurate answers are in most cases impossible to obtain. What users can expect are solutions with bounded rationality. If the required accuracy is raised, the effort involved in the simulation will be increased accordingly.(Hong et al. 2000).
Reliability is defined as the replicability and consistency of the methods, conditions, and results.

Testing reliability is divided into two parts; reliability of the simulation tool and reliability of findings

6.6.1 APACHE Software reliability:

Empirical validation of different environmental modeling software has been previously studied by a joint effort between International Energy Agency IEA Annex 21, and IEA Solar Heating and Cooling (SHC) Task 12, subtask B (Lomas et al 1997). The work was directed by the UK Building Research Establishment (BRE) and managed by the institute of Energy and Sustainable Development at De Montfort University in the UK, and the Energy Monitoring Company in the UK. The project aim was to develop well documented and well tested empirical validation benchmarks for Dynamic Thermal software programs. The empirical validation used two techniques for testing the software, the first is using real buildings measurement and the second was an inter-program comparison. A data set for a particular room in the Energy Monitoring Company (EMC) test rooms were simulated by all the softwares and output results were all compared to empirical data sets measured by instrumentation for the room. This created an acceptable error range by which all software outputs were assessed for accuracy.

The project identified 25 of higher order simulation packages among which APACHE was chosen. The general conclusions from the validation exercise were that APACHE performed within the tight error range that was specified by the study and scored highly in its accuracy in predicting energy performances of the rooms specified while mechanical controls were applied (heating). APACHE results indicated an acceptable error range when free floating condition (no-mechanical ventilation and no control over internal comfort conditions) were compared to those measured inside the test room. But as the report explained that this was a common error in 23 of the 25 softwares examined, therefore it was not considered a criterion of judging the efficiency of the software for this study.

6.6.2 Reliability of Simulation Results:

Research of similar nature to that undertaken in this thesis is validated by three methods: analytical tests, inter-program comparisons and empirical validation, (Table 10) illustrates strength and weaknesses of each validation method.

Table 10: Building Energy and Environmental Modeling, source CIBSE Applications Manual

Technique	Method	Strength	Weakness
Analytical tests	Predictions for a simple situation are compared with expected results which can be calculated analytically using well known mathematical models	Tests correct processing by the input processing the program and the output interface exact known answer to quantify absolute accuracy	Very limited in verifying exact and dynamic real life building energy consumption Complexity increases if whole buildings need to be considered
Inter-program Comparisons	Predictions are compared with those from other simulation programs supplied with equivalent input data	Relatively easy to perform and in principal any building situation can be modeled	A weak test. All programs will have inaccuracies. There is therefore no measure of absolute accuracy. Will only demonstrate whether the tested program performs in line with the others.
Empirical Validation	Predictions are compared with real building measurements	In principal the most powerful validation technique	▪ The true answer obtained is uncertain, due to uncertainties in measurements and data supplied to the program ▪ Empirical validation is difficult to carry out convincingly ▪ Data must be from unoccupied buildings rather than complex occupied ones ▪ The measurements are expensive and time consuming.

The amount of information deducted from the statistical data is insufficient to create the simplest building description adequate for a detailed building simulation; a great deal of engineering judgment is used to complete the modeling of the prototypical building. The utilization of actual building plans and façade properties resolves the modeling of the physical aspects of a building. Although building managers were asked to give information on air-conditioning systems and occupancy of buildings, there still remained a need for engineering judgment using typical design values for system efficiencies, and electricity consumption by fittings and office equipment and occupancy levels. To test reliability of simulation data an inter-software exercise and an empirical validation are carried out.

To increase reliability of simulation outputs of sophisticated dynamic thermal software simplified thermal softwares can be used (CIBSE,1999). An inter software comparisons using CIBSE Admittance method (APACHE-CALC) and a dynamic hourly thermal software (APACHE-Sim) were used to generated monthly predictions of electricity consumption of an existing single skin building in Cairo. APACHE-Sim uses an hourly weather profile while APACHE-CALC uses an average monthly reading. Days similar to the average values were chosen from the APACHE-Sim weather profile to compare between both simulation tools results.

As no actual cooling loads are measured in the World Trade Centre, a method was needed to convert measured electricity data used for the air-conditioning system to cooling loads. Data supplied on the aggregated monthly bills were also provided by building management, divided according to the main three readings of the buildings meters into consumption for elevators, for lighting and equipment and cooling system electricity consumption.

To calculate cooling loads and compare simulated data to actual electricity consumption, all electricity consumption per month was divided by a 'Coefficient of system performance'. Coefficient of performance (COP) for cooling systems is defined as: 'the ratio of heat removal to the rate of energy input in consistent units.' (Stein and Reynolds)

This Coefficient depends on the season known as the seasonal coefficient of performance. It is defined as the *'total cooling output of an air conditioner during its normal annual usage period for cooling/ heating divided by the total electric energy input during the same period in consistent units.'* (ASHRAE 1999).

To convert electricity consumption for the cooling system into loads the following was assumed.

Cooling load= Electricity consumed for Air conditioning system/ Co-efficient of performance COP.

Due to the fact that the air-conditioning systems in the building is old and the building management thought it was inefficient and were considering its replacement a low seasonal co-efficient of performance was assumed.

In Summer COP= 2

In winter COP=3

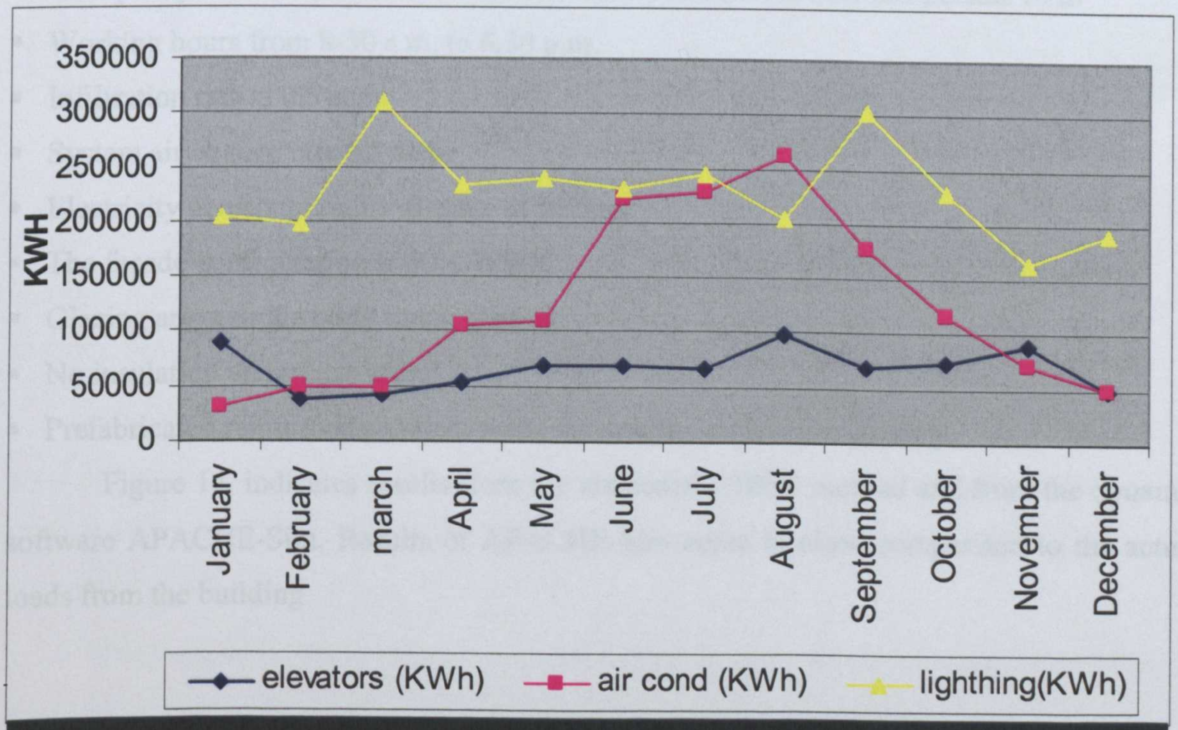


Figure 13: World Trade Centre Actual Bills Averaged 97-99

The Load shape of the air-conditioning system has a direct relation to the prevailing weather profile. The Load shape is also consistent and pattern matching with findings by (Akbari, et al 1993) for office buildings in arid areas in the USA. Both load shapes of elevators and lighting and equipment in the World Trade Centre (Cairo) show variations un-connected to the weather profile which might indicate the effect of users varying demands on the building systems (Figure 13).

The building management explained that the cooling system used in the building had no de-humidification system i.e. no removal of latent loads. Therefore only sensible loads were used to compare simulation results to actual consumption. Other specific variables were simulated to match reality:

- The building is 20 floors high
- Occupancy were calculated at 90% of the office floor area, with one person/10 m^2
- Working hours from 8-30 a.m. to 6.30 p.m.
- Infiltration rate at 0.5 ac/hr
- System air change rate 0.5 ac/hr
- Electricity consumption for fittings at $20W/m^2$
- The façade configuration is 50% WWR
- Glazing areas single body tinted glazing.
- No insulation on opaque areas
- Prefabricated reinforced concrete walls for opaque areas under glazing.

Figure 14, indicates results from the elemental CIBSE method and from the dynamic software APACHE-Sim. Results of APACHE-Sim come in close comparison to the actual loads from the building.

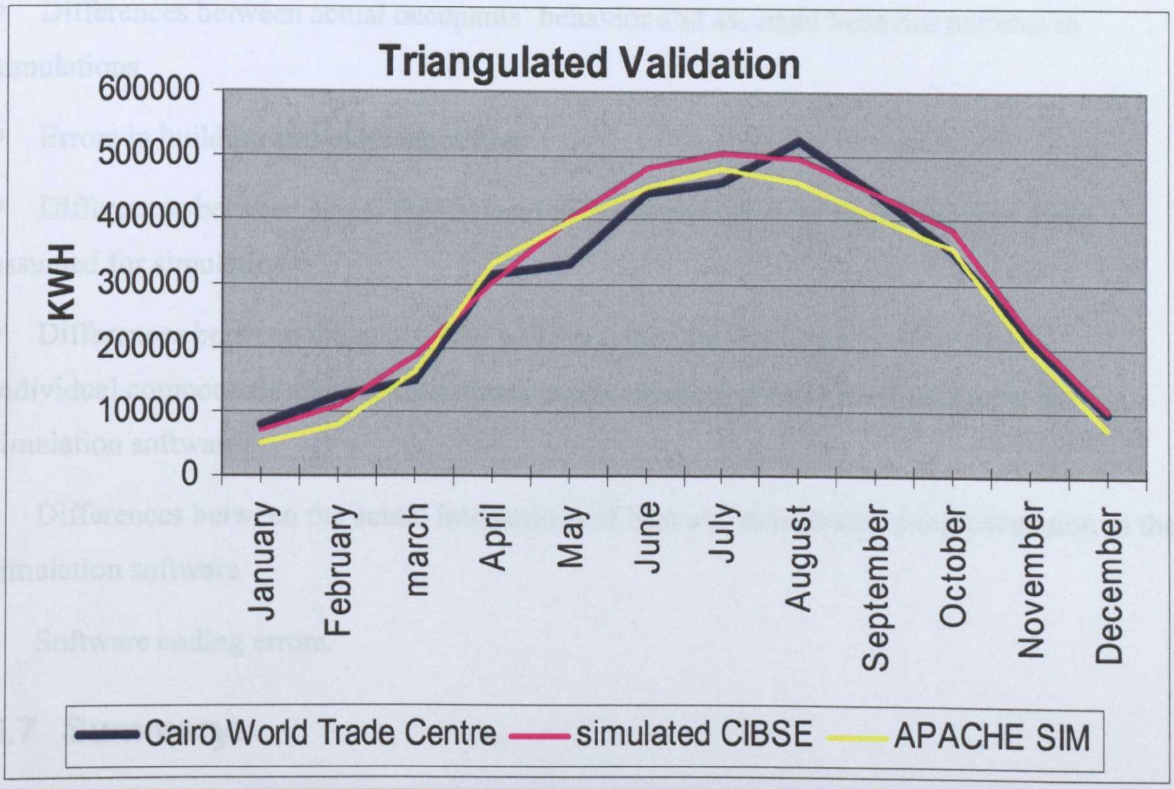


Figure 14: Empirical and inter-software reliability testing

It is interesting to note that both the elemental method (CIBSE) and the dynamic simulation method (APACHE-Sim) indicated a pattern matched prediction to the real consumption of the World trade centre. The dynamic simulation method however gave more accurate results.

Figure 14, indicates that simulated building cooling loads by APACHE-Sim are in good agreement with the real situation, Apart from the months of May and August the loads are accurately predicted with an error between 1-2%, for the months of May and August the error reached 8% which is considered acceptable.

Differences between simulation results and actual measured data maybe attributed to seven main sources of error identified by (Judkoff and Wortman, 1983):

- Differences between the actual weather conditions surrounding the building and weather assumed for simulations

- Differences between actual occupants' behavior and assumed behavior patterns in simulations
- Errors in building and plant input files
- Differences between actual thermal and physical properties of the building to those assumed for simulation
- Differences between the actual heat and mass transfer mechanisms operative in individual components and the algorithmic representation of those mechanisms in the simulation software
- Differences between the actual interactions of heat and mass transfer representation in the simulation software
- Software coding errors.

6.7 Summary:

This chapter illustrated the operational framework for constructing the base case and the variables attached to the model.

- To construct the physical attributes of the base case a survey on Cairo office buildings was conducted. Variables affecting the internal loads were based on CIBSE and ASHRAE standards and the literature review in this thesis.

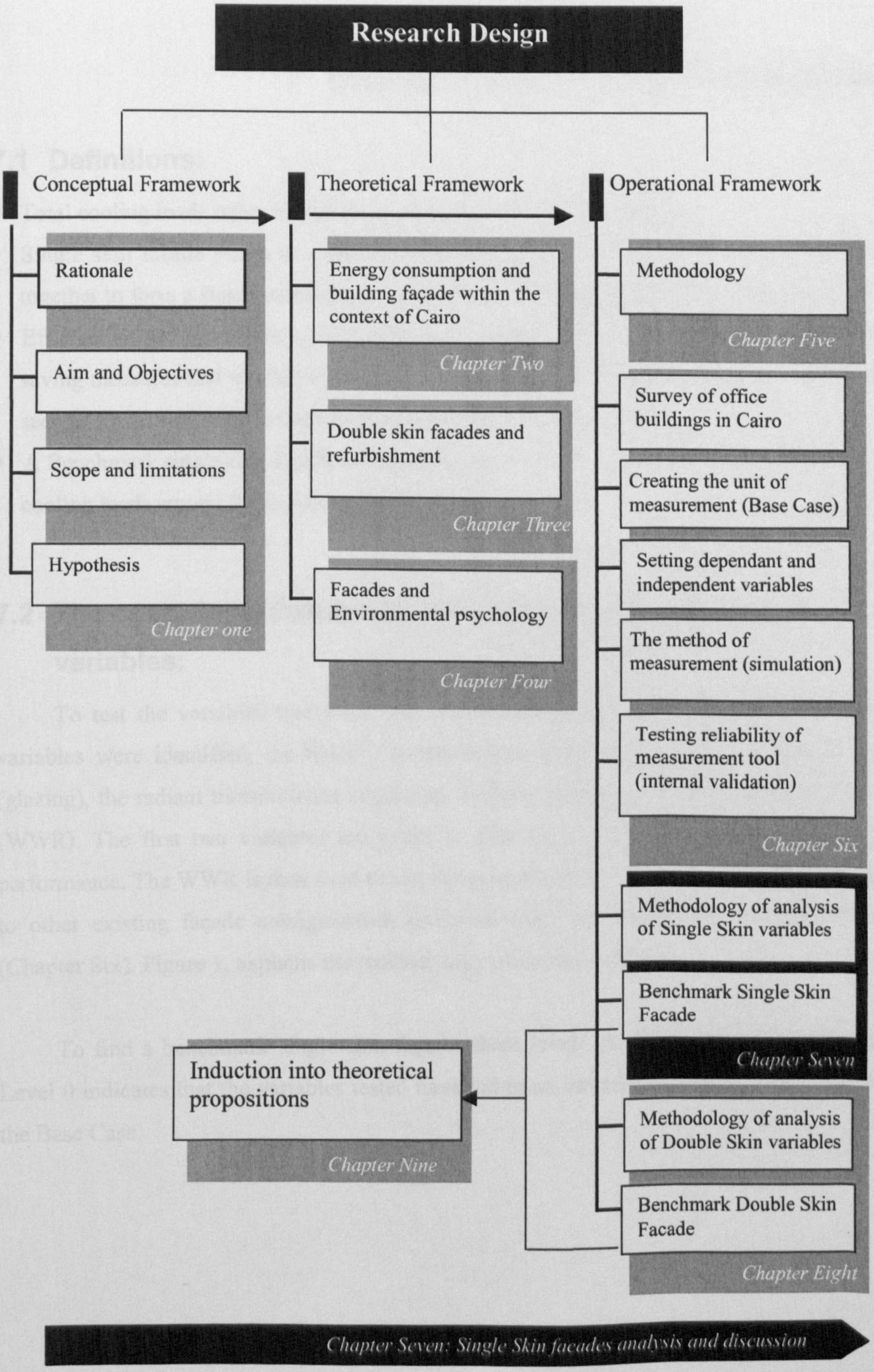
- To examine the performance of double skin facades a methodology literature review was carried out, and building simulation analysis was identified as a reliable method to test thermal and visual performances.

- Reliability of the software chosen was tested by triangulating actual energy consumption data collected from an office building in Cairo and pattern matching consumption with predictions. An acceptable range of error between the predicted energy consumption for the cooling loads and the real data measured from the building was reached.

Chapter Seven: Single Skin

Key Concepts

7.1 Definitions
7.2 Operational model for testing variables
7.3 Base Case Performance
7.4 Bioclimatic Design guidelines
7.5 Effect of Orientation
7.6 Changing the thermal transmittance
7.7 Changing the glazing properties
7.8 Changing the glazing properties during refurbishment


Research Design
Conceptual Framework
Theoretical Framework
Operational Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
The method of measurement (simulation)
Testing reliability of measurement tool (internal validation)
Chapter Six
Methodology of analysis of Single Skin variables
Benchmark Single Skin Facade
Chapter Seven
Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
Induction into theoretical propositions
Chapter Nine
Chapter Seven: Single Skin facades analysis and discussion

7 Chapter Seven: Single Skin Facades:

7.1 Definitions:

- Total cooling loads refers to sensible and latent loads added together.
- Single skin façade refers to a façade composed of a singe or multiple layers combined together to form a single moderating layer between the indoor and outdoor environment.
- Efficient single skin refers to a refurbishment scenario that combines one or more energy saving measures that would indicate significant cooling load reductions (above 5%) that is seen as a practical durable and easily applied refurbishment option.
- A Benchmark single skin façade defines a façade that has a minimum impact on the cooling loads among the façade variables tested.

7.2 The operational framework for testing single skin façade variables:

To test the variables that affect the thermal performance of the façade three main variables were identified, the thermal transmittance of the opaque and transparent areas (glazing), the radiant transmittance of glazing, and the Window to Wall Ratio of the façade (WWR). The first two variables are tested to find out a Benchmark Single Skin façade performance. The WWR is then used to test the generalizability of the benchmark single skin to other existing façade configurations indicated from the Cairo office building survey (Chapter Six). Figure 1, explains the methodology of testing variables.

To find a benchmark single skin façade, three levels of testing have been identified. Level 0 indicates that the variables tested have led to an increase in total cooling loads than the Base Case.

Level 1 indicates that the variables tested have indicated that the façade configuration being tested led to insignificant reductions in total cooling loads than the Base Case, i.e. that reductions achieved were in the range of 5%.

Level 2 indicates that significant load reductions have been achieved due to the variables tested. Level 3 indicates that among the façade configurations tested leading to significant changes, this particular façade configuration leads to the least total cooling loads.

Level 2 and 3 collectively lead to significant total cooling loads, to choose a Benchmark Single Skin façade configuration a significance test is conducted and is explained in (7.7.3).

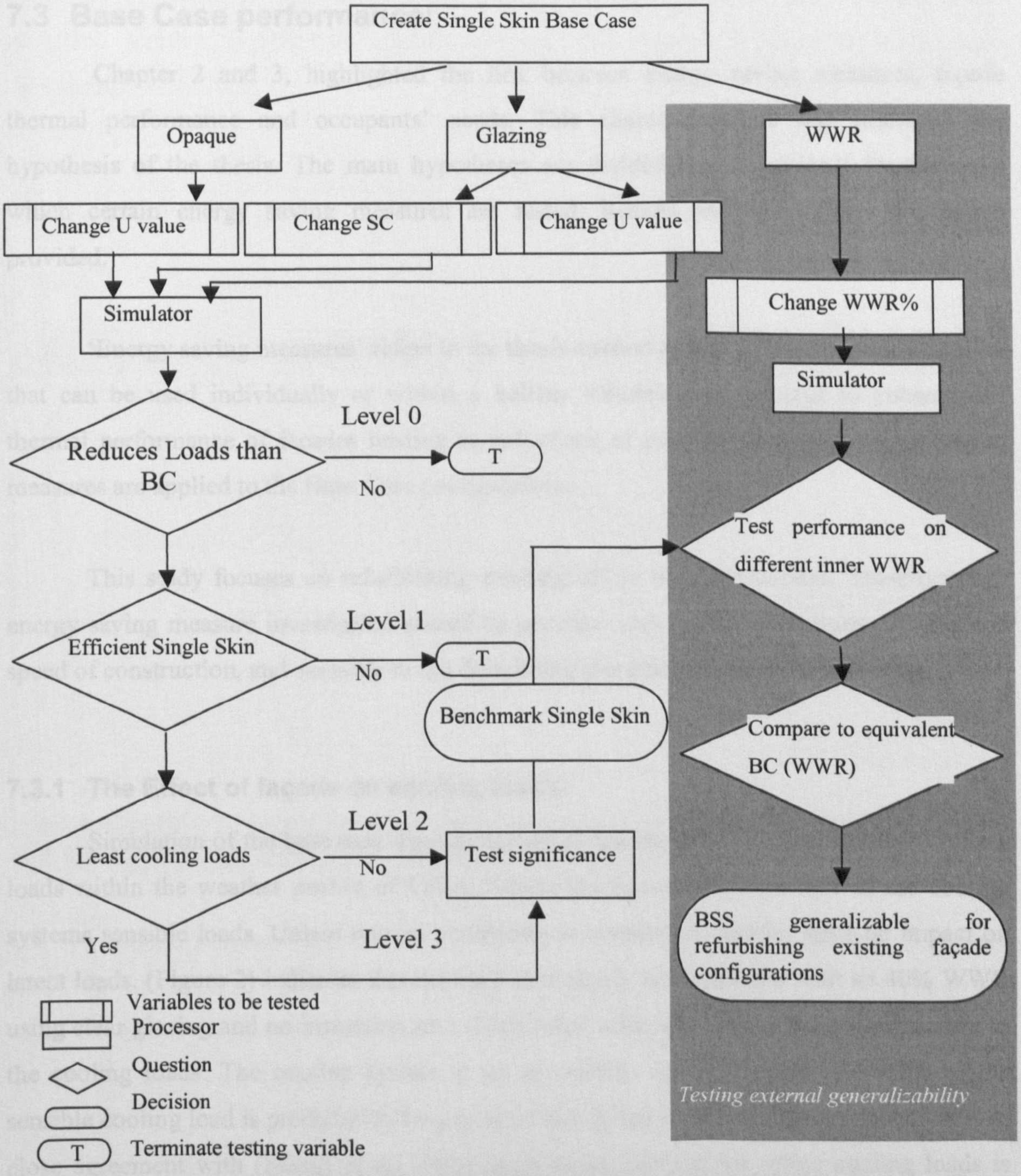


Figure 1: Operational framework to test variables affecting the thermal performance of Single Skin

7.3 Base Case performance:

Chapter 2 and 3, highlighted the link between energy saving measures, façade thermal performance and occupants' needs. This chapter analysis and discusses the hypothesis of the thesis. The main hypotheses are divided into operational hypothesis n which certain energy saving measures are tested. Results and discussions and hence provided.

'Energy saving measures' refers in the thesis context to any façade material alteration that can be used individually or within a holistic refurbishment scheme to enhance the thermal performance of facades leading to reductions of cooling loads. All energy saving measures are applied to the Base Case configuration.

This study focuses on refurbishing existing office building facades. Therefore, any energy saving measure investigated should be practical and applicable in terms of ease and speed of construction, and versatile to the demanding climatic and urban considerations.

7.3.1 The Effect of façade on cooling loads:

Simulation of the base case was carried out to test the effect of the façade on cooling loads within the weather profile of Cairo. Façade configurations contribute to the cooling systems sensible loads. Unless natural ventilation is introduced, facades have no impact on latent loads. (Figure 2) indicates that the base case façade configuration with its 40% WWR using clear glazing and no insulation on a 22cm brick wall, would contribute significantly to the cooling loads. The cooling system is set to provide 3ac/hr. At this rate, 44% of the sensible cooling load is predicted to be generated due to the façade configuration, which is in close agreement with (Elkadi et al. 1999) work where 40% of the office cooling loads is predicted due to façade configurations in hot arid areas.

Ventilation rates are a dominant variable in total building cooling loads in hot arid areas building managers tend to lower the ventilation rates to achieve higher energy savings. Reducing ventilation rates is linked with poor air quality and increased occupant dissatisfaction.

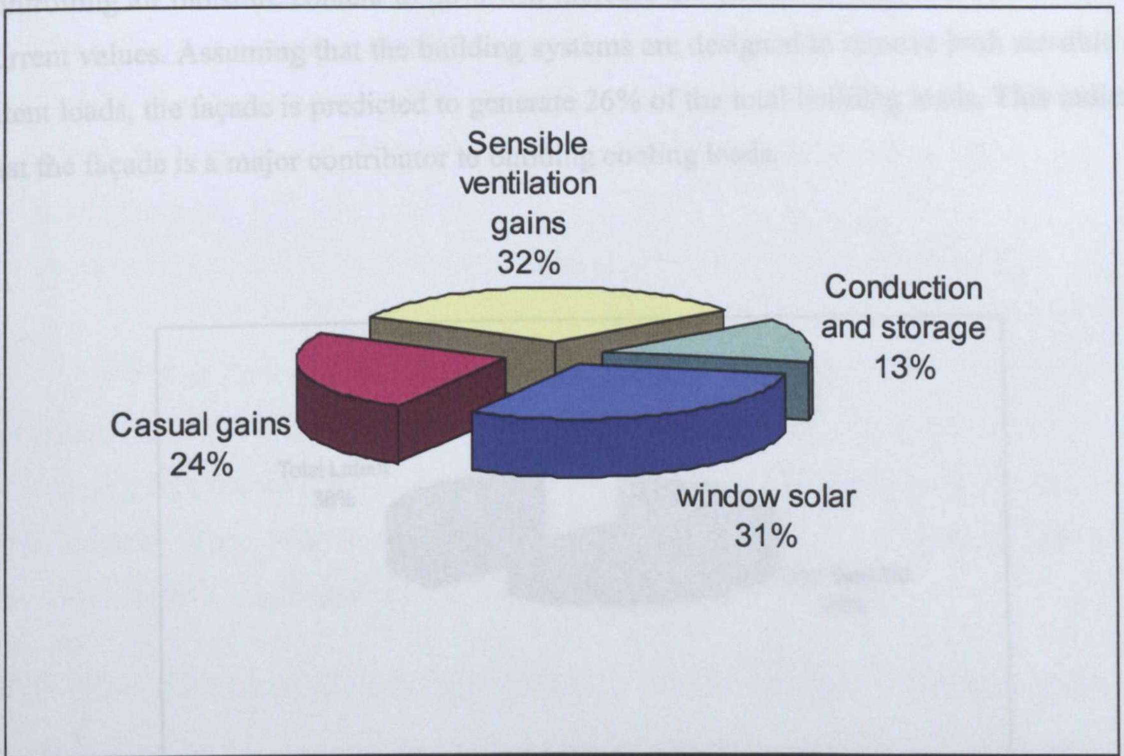


Figure 2: Contribution of Base Case Facade to Building Sensible Loads (Typical Floor)

Figure 2, indicates the effect of direct solar penetration through glazing on cooling loads. The effect of conduction though opaque walls on the cooling loads is only 1/3 of the effect of direct solar radiation through fenestration. This is also attributed to the large window to wall ratio used in the model.

Ideally, cooling systems are designed to deal with both sensible and latent loads. Controlling humidity levels improves indoor thermal comfort and indoor air quality. However, in Cairo, the building managers of the surveyed office buildings asserted that the systems currently used do not deal with de-humidification of indoor air directly. Ambient humidity levels decrease during sunshine hours and the mechanical air change rate removes part of indoor latent loads. However, simulation results (Figure 3) indicated the need to remove latent loads if comfortable and healthy conditions are to be maintained indoors. From the results of the simulation of the base case, it is predicted that dehumidification systems controlling air moisture content to 60% will increase the electricity bill to around 40% of its current values. Assuming that the building systems are designed to remove both sensible and latent loads, the façade is predicted to generate 26% of the total building loads. This indicates that the façade is a major contributor to building cooling loads.

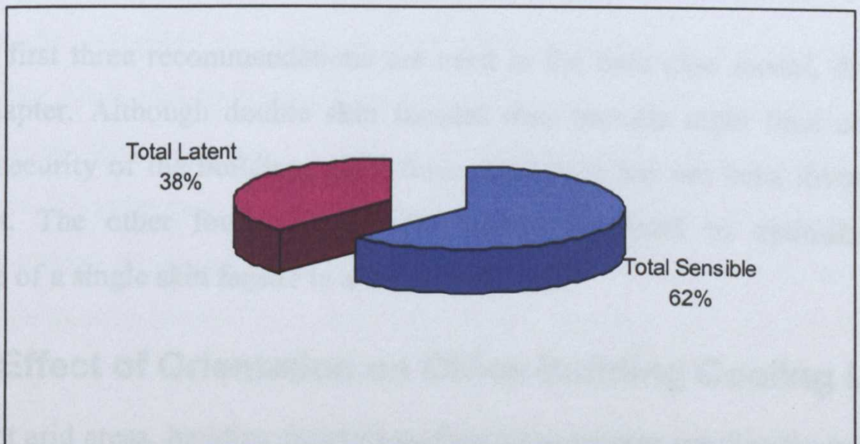


Figure 3: Total cooling system loads (Typical floor in a summer day)

7.4 Bioclimatic design guidelines in hot arid areas:

(Watson et al. 1997), recommended guidelines for designing a bioclimatic building in summer and in particular in hot arid areas. The guidelines may be divided into three basic groups; recommendations for urban setting, natural ventilation, and architectural design of the building and its shell. It is the later group of recommendations that are of concern to this thesis. These guidelines are:

- Shape buildings to minimize exposure to summer sun;
- Use open plan interior to promote air flow;
- Use thermally massive construction to provide a 'thermal fly wheel', absorbing heat during the morning from solar radiation and convection from indoor air;
- Use night time cooling to flush out heat gain from thermal mass due to time lag effects.
- Orient buildings to minimize exposure to summer sun;
- Use high mass construction with external insulation;
- Use sun shading in summer. The sun angles are different in summer than in winter, which allows for summer sun shading without loosing the benefit of winter sun to be used for heating spaces;
- Provide vertical air shafts to promote' thermal chimney' or stack effect air flow.

The first three recommendations are used in the base case model, discussed in the previous chapter. Although double skin facades may provide night time cooling without decreasing security of the building, night time ventilation has not been investigated within this context. The other four criteria were studied in detail to optimize the thermal performance of a single skin façade in a hot arid climate.

7.5 The Effect of Orientation on Office Building Cooling Loads

In hot arid areas, building façade's surface temperatures are directly in relation to the diurnal and annual patterns of solar radiation and air temperatures. The elevated surface temperature increases indoor air temperatures and subsequently cooling loads (Givoni 1998).

While urban settings may dictate the façade orientation of any building, understanding the climatological impact on the facades helps in choosing appropriate technologies and construction materials to minimize heat gain and decrease system cooling loads.

To test the effect of façade orientation on the cooling load, direct solar radiation and ambient air temperature are related to sensible cooling loads of a typical base case floor (4^{th} floor of the model). The ambient dry bulb temperatures are simulated for a typical summer day with maximum dry bulb reaching 37.5 ^{0}C (ASHRAE Design Temperature).

From a thermal comfort perspective, summer in hot arid areas is considered the most thermally stressful period of the year, discussions in the literature review indicated the difficulty of providing thermal comfort in an office building environment without air conditioning in summer. To reduce the building energy consumption, cooling loads due to façade orientation are examined to understand the interplay between façade as an indoor thermal moderator and building orientation. Analysis of results discusses the effect of façade orientation on peak summer and winter, and annual cooling loads.

7.5.1 Effect of Façade Orientation on Peak Summer Cooling Loads:

To understand the relation between facade orientation and cooling loads, simulation results were disaggregated to solar gains through fenestrations, compared to the sensible system cooling loads and to ambient dry bulb temperatures for each orientation zone. The three parameters form the three Y-axis in (Figure 4), from left to right, the dry bulb temperature in ^{0}C, solar gain through fenestration in Watts, and zone cooling loads in Watts. The X-axis presents the time of the day. Simulation results presented in (Figure 4), are based on the sensible cooling loads of the zone behind each façade orientation of the model on the typical building floor (Level 4 of the model).

The rise of the dry bulb temperature is directly related to conduction gains through all façade orientations, and has a similar effect in raising cooling loads on all facades as it peaks between 2p.m. - 4p.m. (daylight saving time).

The East façade is affected by the morning direct solar radiation penetrating indoors causing a sudden and steep rise in cooling loads. This is evident by the rise in the "direct solar gains" curve (Figure 4). As the sun moves away from the East orientation the cooling load curve decreases between 11a.m. to mid day. The cooling loads starts increasing between 1p.m-5p.m. This is attributed to the combination of heat transmission through the fabric and the rise in ambient dry bulb temperatures. This leads to an almost constant sensible cooling load from the façade to indoors during building operational hours.

The West facade orientation indicates a gradual rise of indoor cooling load demand during the morning hours from start up till 2 p.m. However, between 2 p.m-4 p.m., the cooling load demand increases as the façade is exposed to the raised afternoon ambient dry bulb temperatures combined with direct solar radiation due to the sun's movement. The climatic influence on this façade orientation is the worst in a hot arid climate as the peak cooling load of the West façade in summer is about 20% higher than all other orientations.

Although the duration and time of incident direct solar radiation on South and North façade is different, from a cooling load perspective, the two orientations perform similarly during summer conditions. Simulation curves are pattern matched to findings from a full scale building test facilities in a hot arid area, carried out by (Givoni 1998:66)

This investigation did not examine other than the main four compass façade orientations, however discussion of other orientations of building facades in hot arid contexts has been studied in detail in (Givoni 1976) and (Sahu and Prakash. 1979).

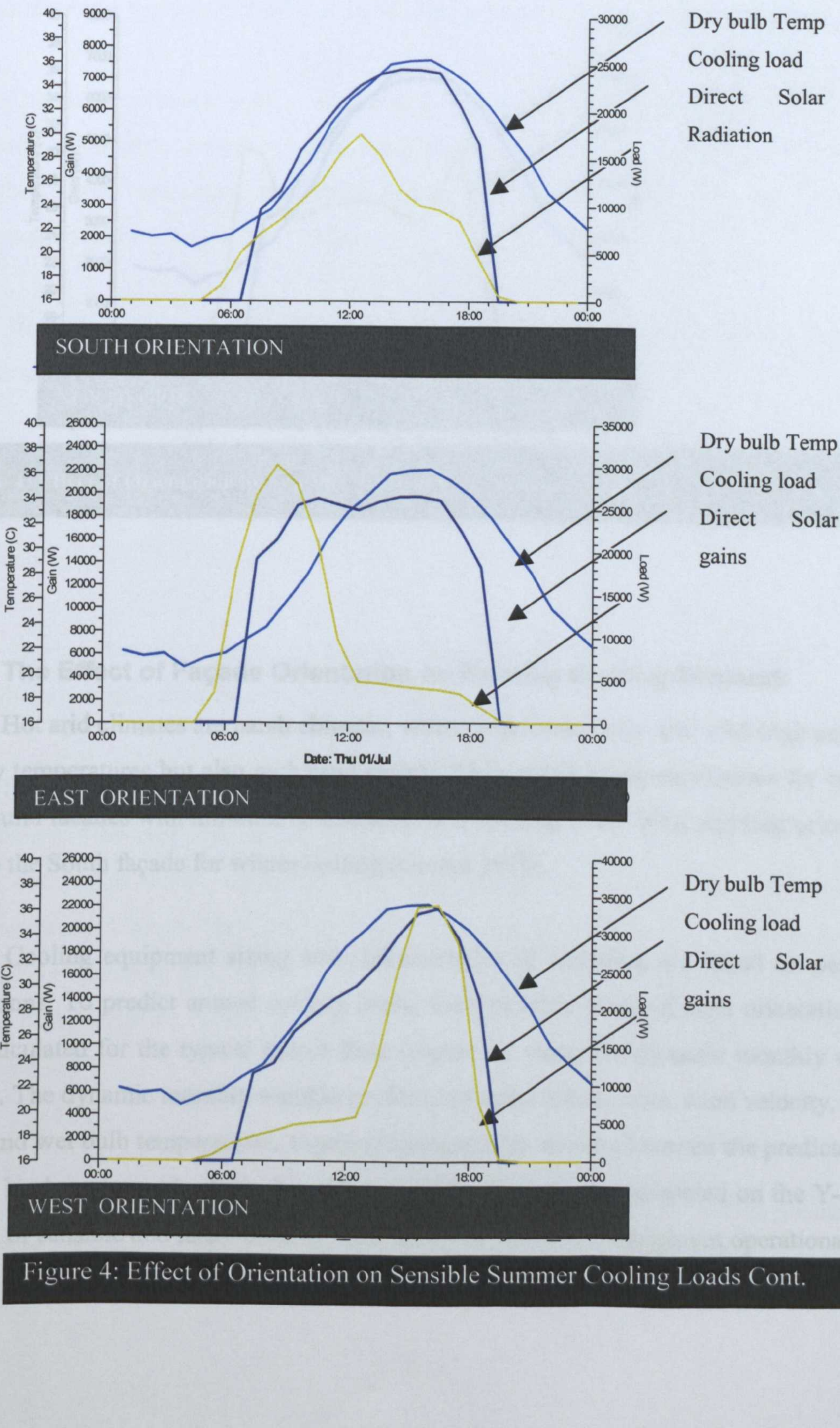
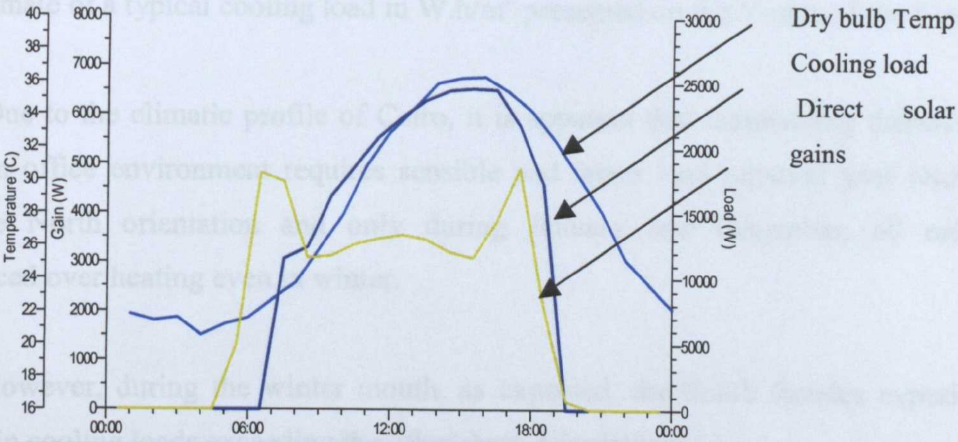


Figure 4: Effect of Orientation on Sensible Summer Cooling Loads Cont.



NORTH ORIENTATION

Figure 4: Effect of Orientation on Sensible Summer Cooling Loads

7.5.2 The Effect of Façade Orientation on Monthly Cooling Demand:

Hot arid climates are harsh climates, where facades not only deal with high amplitude of daily temperatures but also with sand storms. The general recommendations for building, are to build facades with minimum dimensions and opening to the West and East orientations and use the South façade for winter heating (Givoni 1976).

Cooling equipment sizing and characteristics of operation are based on peak load calculations. To predict annual cooling loads, total monthly loads of each orientation zone were calculated for the typical model floor (Figure 5), using the dynamic monthly weather profiles. The dynamic monthly weather profiles estimates cloud cover, wind velocity, as well as dry and wet bulb temperatures. Figure (5) presents the relation between the predicted total cooling loads and month of the year. The monthly cooling load, presented on the Y-axis, is the sum of sensible and latent cooling loads summed during the equipment operational hours for each month, divided by the zone area and cooling equipment operational time. The result is an estimate of a typical cooling load in $W.h/m^2$ presented on the Y-axis of the figure.

Due to the climatic profile of Cairo, it is apparent that maintaining thermal comfort within an office environment requires sensible and latent load removal year round. Apart from the North orientation and only during January and December, all orientations experienced over heating even in winter.

However, during the winter month, as expected, the South facades experienced an increase in cooling loads exceeding the other three orientations.

The East, West and South orientations performed similarly in months of March and September. The North orientation remains predominantly lower in monthly cooling demands year round.

During summer months, the East and West Façade had a similar monthly total load, predominantly higher than the South and North facades.

During summer months, the South and North façades indicated similar cooling load requirements. However, the annual performance of the South Façade with its increase in cooling demand in winter would not lead to larger climate control equipment, but rather longer operational hours. The peak loads calculations which govern equipment sizing is then dependant on reducing peak loads on the dominant cooling load generating facades; in this case the East and West. These results confirm general façade orientation recommendations by (Givoni 1976)

At this point, it is important to predict the annual total cooling loads to predict which orientations offer opportunities for energy saving through climatic control.

Figure 5: Monthly total cooling loads on different orientations

7.5.3 The Effect of Façade Orientation on Annual Cooling Demand:

Summing total monthly cooling loads of the four orientation zones (Figure 6) indicated that East, West, and South facades were similar in their annual demand for cooling loads. The North façade is predicted to generate 12% less annual total cooling loads, which maybe attributed to the North Façade's shorter exposure to direct radiation, combined with lower dry bulb temperatures during the early morning hours between 6a.m.-8a.m. and again around 5 p.m..

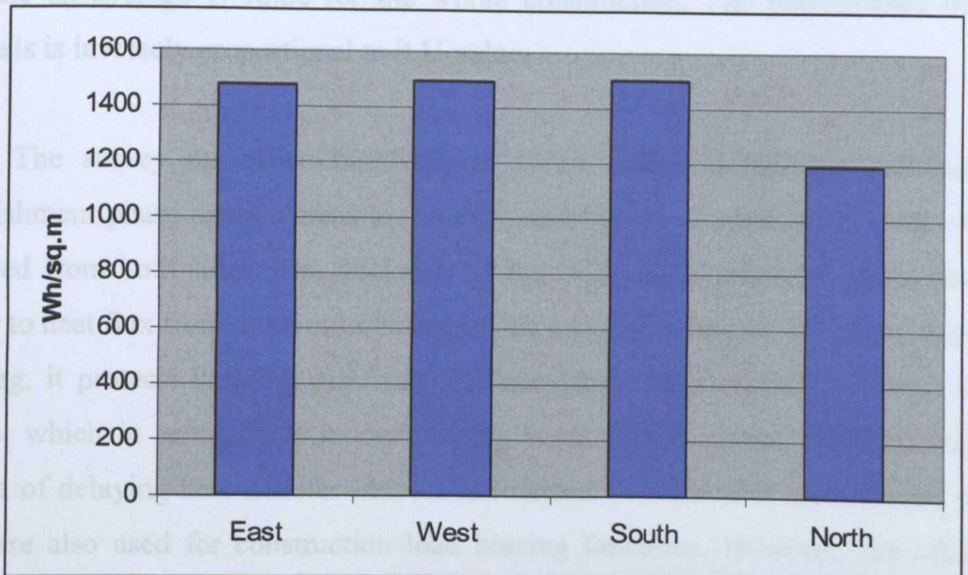


Figure 6: Annual total cooling loads for the typical floor of the model

7.6 Case 1: Changing the thermal transmittance of the façade opaque areas U_o

The process of heat transfer through conduction indoors occurs from all façade materials. For opaque wall areas, conduction is the only heat transfer process through a solid substance opaque to radiation. Thermal insulation is used on opaque façade surfaces to retard unwanted heat transfer by conduction into or out of a building.

Insulation indicates the potential to reduce energy consumption required for heating/cooling demands of the building through decreasing conduction gains from the building fabric, thus maintaining occupants' comfort with less expenditure on energy consumption. The efficiency of insulating materials is measured by comparative performance of its total thermal resistance (R-value) or more commonly by their thermal transmission (U-value). The U-value is calculated as the reciprocal of the total thermal resistances of the wall materials. Thermal resistances are summed based on resistances of consecutive layers of the construction (treated as an electrical resistances connected in series) then is used to calculate an average U-value for the whole construction. The performance of insulating materials is inversely proportional to it U-value.

The survey on office buildings in Cairo indicated that for buildings in their refurbishment phase opaque areas are mainly constructed of solid brick walls of 22cm and plastered from both sides. The thickness of the brick layer creates a conduction retardant barrier to heat flux from outdoor to indoors. This property is known as thermal capacitance or time lag, it protects building materials and occupants from excessive diurnal temperature swings, which in turn affects indoor cooling loads and occupants' thermal comfort. This method of delaying heat transfer indoors is founded in vernacular architecture, where solid walls are also used for construction load bearing functions. However, the office building survey in Cairo indicated brick walls are still a popular construction material for opaque walls in modern constructions.

The lack of insulation application to building facades is associated with poor building façade thermal performance in developing countries in hot arid areas. Although the brick infill of walls acts as a capacitive insulation, no heat resistive insulation is found on walls of thermal mass in the office buildings surveyed in Cairo. It is the aim of this investigation to test the benefit of adding external insulation to facades.

Resistive insulation materials are light in weight, but have less thermal storage capacity that brick or adobe layers. In construction processes they do not serve any structural function and create minor loads on facades, and therefore easy to apply during refurbishment. It helps in enhancing the thermal transmittance of the walls without adding considerable thickness and loads to facades.

In refurbishment, positioning the insulation on the exterior of the walls surfaces is favored as it causes minimum disruption for the occupants, and does not reduce the interior rented space. Combining thermal mass with exterior insulation versus the interior positioning of insulation in hot arid climates has been studied by (Hassan et al. 1969) and (Etzion 1994).

The exterior position indicated greater reduction for indoor temperatures and reduced temperature swings.

Applying external insulation should be weighed carefully while refurbishing office buildings façade. Aesthetic value of ornate, removal and re-positioning of wastewater pipes must also be considered. Modifications to window sills' depths and resealing the window frames are a crucial issue to insure the quality of installation of the insulation (Highfield, 2000).

It is important to note that values of thermal conductivity (lambda-values) for insulation materials may vary due to variations in manufacturers' density and thickness, changes in moisture content and the effect of aging on material properties. In building simulation is it advisable to take these considerations into account and simulate values based on worst thermal performance of the insulating materials (McMullan 2002).

Using thermal mass with polystyrene applied on the outer surface of the building, while increasing the thermal resistance of the wall is considered as a measure to reduce heat gains, in hot arid climates the order by which these materials are placed is a determinant of the wall's thermal performance. In Hot arid areas the thermal storage of the walls is enhanced by the thermal contact between the interior air and the wall surface of the thermal mass. Therefore insulation must be placed on the outside surface of the building and covered by special acrylic paints to give both appearance and weathering resistively to the insulation material. (Etzion et al. 1997) warn that applying the insulation material on the interior of the building would effectively reduce the thermal capacity of the façade and the thermal lag offered by its thermal mass.

To test the impact of applying thermal insulation on opaque areas of the model the U_{opaque} value is decreased from 1.7 $W/m^2.K$ to 0.37 $W/m^2.K$ and assessed on monthly bases for each façade orientation on the typical floor level. Results are parametrically analyzed compared to an un-insulated base case.

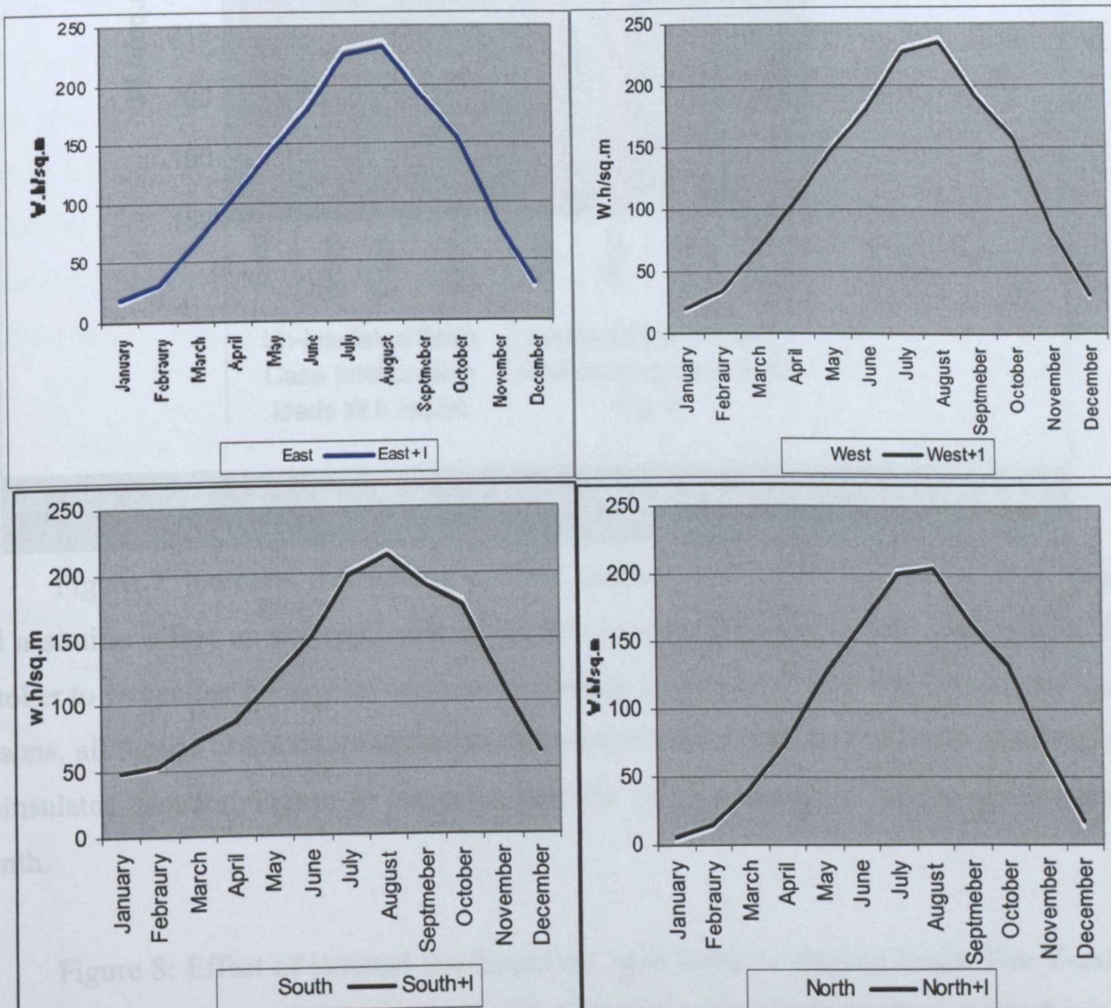


Figure 7: Monthly impact of reducing U opaque

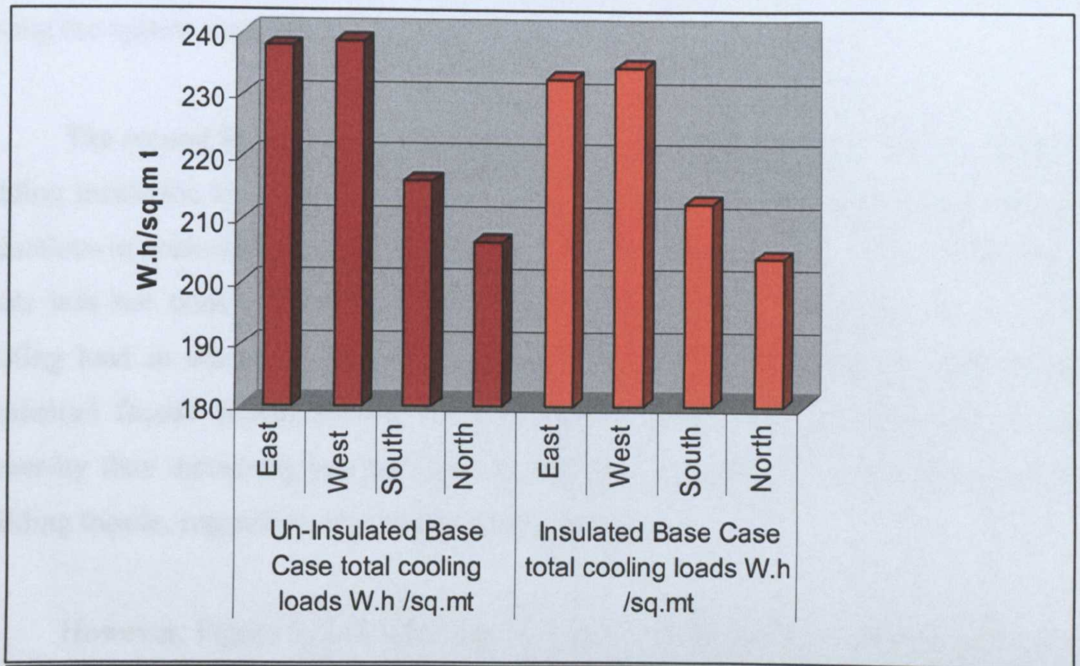


Figure 8: Effect of external insulation on peak summer cooling loads

Figure 7, indicates that adding external insulation to reduce the U_o value of facades had a similar effect on cooling loads on all orientation. Between January and March, then October to December a marginal increase in cooling loads is observed. In autumn and spring seasons, all façade orientation indicated almost identical cooling load between insulated and un-insulated facades. Figure 8, indicates that the only reduction is during peak summer month.

Figure 8: Effect of external insulation on peak summer cooling loads. The Y-axis is the cooling loads for a typical m^2. The X-axis indicates the four orientations of facades in the two simulated cases (insulated and un-insulated base case). The peak loads on all orientations were reduced by applying external thermal insulation by 2%. The insignificant reduction in total cooling loads may be attributed to two factors.

First due to the thermal capacity of the opaque area, it retards conduction to after occupancy hours. The reduced ability of the building mass to cool during night time when outdoor temperature is less than indoor temperatures, contributes to increasing cooling loads during the system start up.

The second factor is due to the high window to wall area used on the base case (40%). Adding insulation to walls with smaller WWR (below 20%) in hot arid areas indicated 6% reductions in peak cooling loads (Hamza et al. 2001), however their impact on winter cooling loads was not tested, which may lead to offsetting peak load reductions to an increased cooling load in winter. Arguably reduced WWR ratios maybe seen as more suitable for residential façade configurations, as it provides less levels of visibility inside spaces to passer-by thus increasing privacy indoors, but may not provide aspirations from an office building façade, regardless of possible energy savings.

However, Figure 9, indicates that in winter cooling load indicated an increase of 3-4 W.h/m^2 on all façade orientations when external insulation is applied. This increase is pronounced on the North façade where total cooling loads are tripled. Adding thermal insulation decreases conductive losses to the external environment. Trapped heat from internal loads into the building thermal mass and indoor air, which in turn increases cooling loads

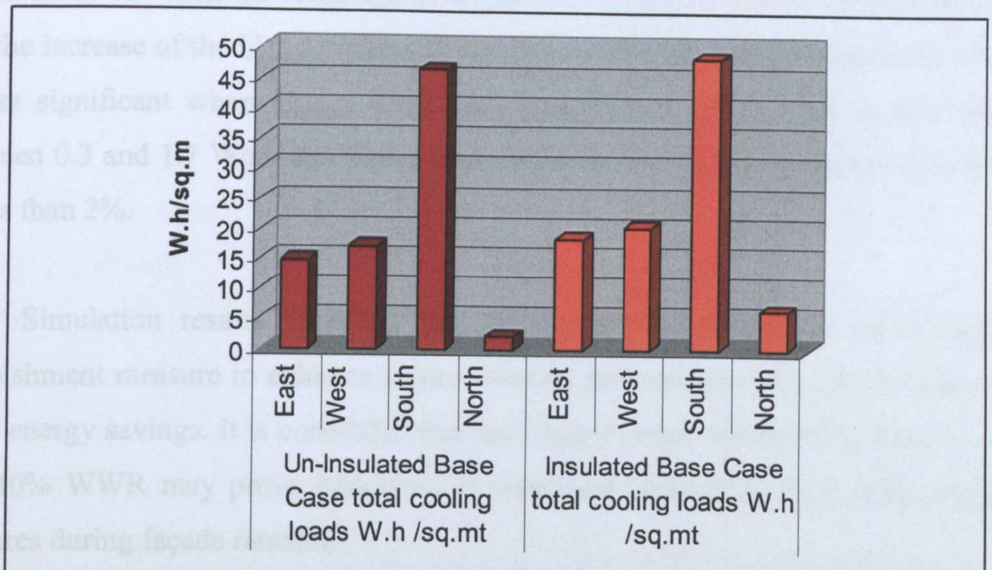


Figure 9: Effect of external insulation on peak cooling loads in winter

Due to the varying effect of external thermal insulation on thermal storage between winter and summer, assessing its performance on annual basis indicates that thermal insulation in this case is less beneficial as the decreases in summer cooling loads are offset by the increase in cooling loads in winter.

Table 1: Significance of reducing U $_{opaque}$ on total annual cooling loads

% of annual change in total cooling loads			
East	West	South	North
1.1	0.7	1.0	-0.4

Table 1, indicates that the annual decrease in cooling loads due to adding thermal insulation on East, West and South facades did not exceed 1% when compared to the same façade orientation of the base case. Conversely, the North façade indicated a slight increase in its annual cooling load to 0.4%.

Simulations results in a hot humid climate reached similar conclusions on the benefit of using external insulation. (Lam and Hui 1996) simulated a base case of 0.44 WWR on a square plan model (35m X 35m). U-values for walls were decreased in intervals from

4 $W/m^2.K$ to 0.3 $W/m^2.K$. Although as expected, the annual energy consumption increased with the increase of the U_{opaque} values. Reductions in energy consumption were also found to be less significant when U_{opaque} were varied to similar values used in this investigation (between 0.3 and 1.7 $W/m^2.K$). Reductions of annual energy consumption were predicted to be less than 2%.

Simulation results indicated that adding thermal insulation, as a single energy refurbishment measure to enhance a poor thermal performance of a façade does not lead to major energy savings. It is concluded that applying thermal insulation to facades with larger than 40% WWR may prove beneficial if combined holistically with other energy saving measures during façade retrofits.

Based on simulation results, the following changes to single skin parameters are studied on the un-insulated base case scenario.

7.7 Changing glazing properties

Glazing areas transmit energy indoors by conduction, convection and radiation. The portion of the short-wave energy, whether arriving directly from the sun or diffusely after atmospheric scatter and terrain reflections eventually finds its way through the glazing areas into subsequent indoor spaces. Depending on the glazing physical properties, the short wave (infra-red radiations) impinging on the outermost surface of the glazing is partially reflected to the outside atmosphere, partially transmitted as direct solar radiation into subsequent spaces and partially absorbed by the glazing thickness.

Direct solar radiation transmitted indoors falling on room surfaces and contents are mainly absorbed by the interior surfaces, while a small ratio is re- reflected to indoors. These re-reflected radiations are mainly absorbed by the fabric and contents. However, a small portion of re-reflected radiation indoors finds it way out through the glazing surfaces. This retransmitted radiation through glazing to the outside is small and can be ignored for the purpose of design and simulation calculations (CIBSE 1999). The simulation software used therefore treats all transmitted incident solar radiation as completely absorbed within model surfaces.

The following properties of glazing are presented as data input to the thermal simulation software.

- Solar absorption
- Solar transmission
- Thermal resistance
- Surface emissivity
- Convective and radiant heat transfer within internal cavities.

Built in APACHE's material library and Pilkington Specifier's Guide (Glass 1992) were used for glazing performance data input. Glazing thermal performance is measured by its thermal transmittance expressed as Ug and Shading Coefficient of glazing (SC).

The thermal transmittance Ug is used as a measure of heat transfer through glazing. It is quantified as the rate of heat loss or gain per m^2 under standard conditions, through a $1m^2$ of a structure when there is a temperature difference across structure of 1 Kelvin

Shading Coefficient of glazing (SC) is a measure of the relative amount of solar heat gain through a window compared to a 3 mm clear glass. it is measured at the centre of glazing which disregards the effect of framing and air spacing between panes. It is mostly used to express glazing performances in glazing manufacturer catalogues.

The Solar Heat Gain Coefficient SHGC is defined as the ratio of the solar heat gain entering the space through the fenestration area to the incident solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space. SHGC values are measured at centre of glazing. (ASHRAE 1999). The SHGC is used to express the glazing performance by the US National Fenestration Rating Council for product labeling. Shading

Coefficient of the centre of glass multiplied by 0.86 shall be an acceptable alternate for determining SHGC requirements for the overall fenestration area.(ASHRAE 1999)

7.7.1 Case 2: Changing the Shading Coefficient of Glazing

The daily mean rate of solar gain is proportional to area of glazed surface and the glazing shading coefficient (SC) or Solar Heat Gain Coefficient (SHGC). It is generally accepted that the hierarchy for choosing glazing to control solar penetration indoors is: *'surface tinted glazing provides better solar protection than clear glazing; body tinted glass provides better protection than surface tinted glazing; reflective glass provides better solar protection than body tinted glass'* (CIBSE 1987). However, these recommendations are general and were tested on the base case to quantify and comparatively predict impacts of each glazing Shading Coefficient on annual cooling loads and peak Summer and Winter cooling loads. From an energy saving perspective, ideally, glazing properties should be customized to balance between the need for day lighting, cooling and heating loads. To accomplish this balance in an hot arid climate, the glazing properties should control the quantity, spectral content, and spatial distribution of incident solar radiation.

Although it is generally recommended that for hot arid areas choosing a lower Shading Coefficient is required to decrease cooling loads The recommendations on the minimum SHGC for hot arid areas found in literature were variable.(ASHRAE 1999) recommends for WWR between 10%-40% that the solar heat gain coefficient for all facades expect the North to be SHGC=0.25. However, (USEPA 2000) advices that the Solar Heat Gain Coefficients lower than 0.4 (corresponding to SC=0.5) are not recommended in hot arid area, as they lead to significant reductions in daylight levels and offsetting energy savings by increasing artificial lighting operation hours.

Static selective glazing refers to body tinted and selective reflective coatings that are deposited on the glass to enable the selective reflection of unwanted visible, solar infra-red radiations incident on the glazing pane. To test the performance of these solar control glazing within the climatic context of Cairo, the thermal transmittance is fixed in all scenarios U_g=5.6 W/m^2.K, while varying the Shading Coefficient (SC) .The impact is measured on a typical m^2 cooling load basis.

Since the 1990, major advances in engineering coatings to reflect infra-red and ultra-violet radiations while allowing for higher visual light transmittance levels were attained. This type of solar control glazing is referred to as spectrally selective glazing in literature, it is engineered to increase visual light transmittance from its current values between 0.21 -0.44 to 0.7. The current selective glazing coatings are not applicable without the protection of an outer glazing layer against weatherization and cleaning scratches, and their price is considered prohibitive for application in developing countries.

The thermal and visual performance of simulated glazing is illustrated in Table 2: glazing properties.

Table 2: glazing properties.

Glazing type	Glazing properties		
	U-value	SC	VLT
Clear Glazing	5.6	0.96	0.89
Single Body Tinted	5.6	0.8	0.61
Single Reflective	5.6	0.6	0.44

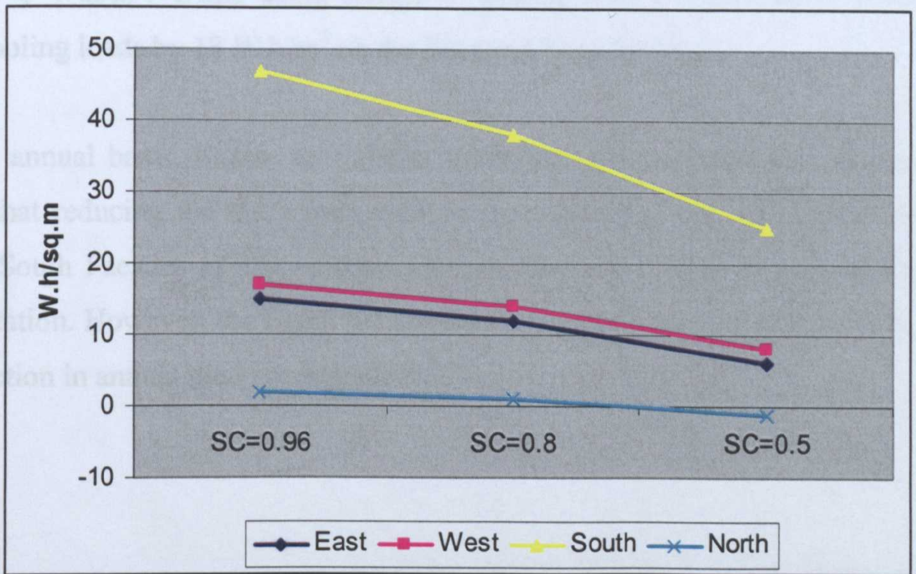


Figure 10: Impact of reducing SC on winter cooling loads

Analyzing the peak winter loads in Table 3, and Figure 10, reducing the SC on the South facing façade approximately halved cooling loads in winter. East and West orientation indicated similar reductions in winter cooling loads. Reducing the SC on the North façade from 0.96 to 0.5 indicated a minor need for heating load, that maybe attributed to the glazing thermal and daylight control performance, leading to reductions in the useful penetration of solar heat gains leaving the indoors with higher heat loss rates through the glazing area. Apart from unifying the architectural expression of different oriented facades, simulation analysis questions the benefit of using solar control glazing to control solar gain on the North orientation.

The impact of reducing the glazing Shading Coefficient is more pronounced in summer (Figure 11) than in winter (Figure 10), as it reduces penetration of solar radiation indoors. On all façade orientations using SC=0.8 produced less significant reductions in cooling loads compared to glazing areas with a lower Shading coefficient (SC=0.5). On East and West facades body tinted glazing (SC=0.8) is predicted to decrease peak summer cooling loads by 7-8 W.h/m^2. While using reflective glazing with a lower SC=0.5 reduced peak summer cooling loads by 18 W.h/m^2 on the East and West facades.

On annual basis, Figure 12 : Effect of changing SC on annual total cooling loads indicated that reducing the (SC) from 0.96 to 0.8 indicated consistent reductions on East, West and South Facades of 5% compared to the Base Case typical floor cooling loads on each orientation. However, the North façade was less sensitive to reductions of SC, indicated a 3% reduction in annual total cooling loads.

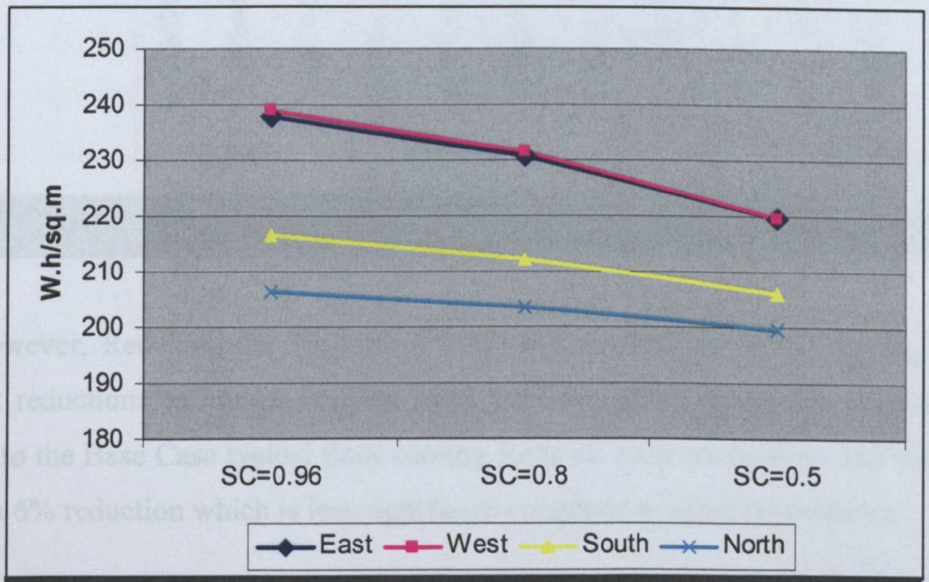


Figure 11: Impact of reducing SC on summer cooling loads

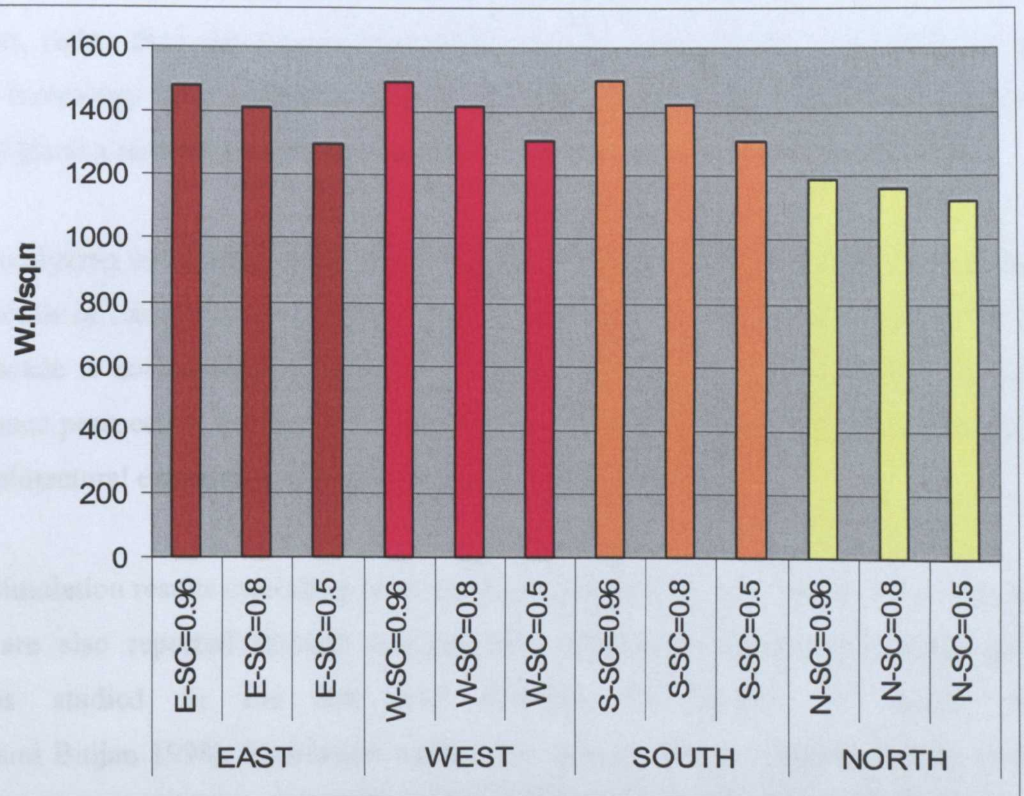


Figure 12 : Effect of changing SC on annual total cooling loads

However, Reducing the (SC) from 0.96 to 0.5 (using reflective glazing) indicated significant reductions to annual cooling loads on East, West and South Facades of 12% compared to the Base Case typical floor cooling loads on each orientation. The North façade indicated a 6% reduction which is less significant compared to other orientations.

The use of body tinted glazing is found to dominate refurbishment of glazed facades in Cairo. Simulations indicate its minor effect on decreasing peak and annual cooling loads in comparison to reflective glazing. Body tinted glazing absorbs heat inside the pane then starts re-radiating it indoors. Due to its ability to absorb heat there is an increased risk of breakage due to higher thermal stresses in the pane. From simulation results, its choice for glazing areas has not indicated recognizable energy savings.

The use of reflective glazing might have been restricted in Cairo due to high taxes on its import, rather than the unawareness of its thermal performance. Hopefully, the trend towards increasing local advanced glazing systems production will offer an appropriate choice of glazing technologies to architects.

Analyzing simulation predictions (Table 3) indicates that compared to the annual cooling loads of East, West and South facing facades, the annual cooling loads of the North facing facade is not sensitive to changing Shading Coefficients. Although from a thermal performance perspective using solar control glazing may not be justified, but the unification of the architectural expression of a building may dictate its use.

Simulation results indicating superiority of reflective glazing compared to body tinted glazing are also reported through test cell and simulations results on various glazing properties studied in the hot arid climates of Damam in Saudi Arabia (Tinker and Buijan 1998). Simulation results also concur with simulations results of office buildings in summer in Istanbul-Turkey where reflective glazing was again proved to be superior to tinted glazing in reducing cooling loads (Tavil 1999).

	East			West			South			North		
	SC=0.96	SC=0.8	SC=0.5	SC=0.96	SC=0.8	SC=0.5	SC=0.96	SC=0.8	SC=0.5	SC=0.96	SC=0.8	SC=0.5
January	15	12	6	17	14	8	47	38	25	2	1	-1
February	30	25	18	31	26	19	52	44	32	11	10	8
March	66	60	50	68	60	51	72	65	54	39	37	34
April	105	98	87	106	99	87	87	83	76	73	71	67
May	148	141	129	150	142	130	120	117	112	123	117	112
June	184	177	165	185	177	172	153	150	145	159	156	149
July	230	223	212	232	224	213	201	198	198	203	200	195
August	238	231	220	239	232	220	216	212	206	207	204	200
September	196	189	179	194	188	177	194	187	177	165	162	159
October	158	152	143	159	153	143	179	170	156	132	130	127
November	83	79	72	82	78	72	115	106	92	65	64	62
December	28	24	19	28	25	19	61	53	39	14	13	11
Total	1481	1401	1300	1491	1418	1311	1497	1423	1312	1193	1164	1123

Table 3: Changing SC and annual cooling loads W.h/m^2

7.7.2 Case 3: Changing the Thermal Transmittance (Ug) of glazing

The thermal transmittance (Ug) of the glazing used on the base case is high Ug = 5.6 $W/m^2.K.$, corresponding to almost 4 times the thermal transmittance of an un-insulated wall, which indicates the significant effect of glazing on cooling loads. Reducing the thermal transmittance of glazing is achieved by increasing the layers of glazing which aims at reducing the heat transfer through the glazed areas. Increasing layers to double and triple glazing units is common practice in cold climates; recently it has been used in hot arid climates in Saudi Arabia and Emirates in air-conditioned buildings claiming a significant reduction of cooling loads.

The thermal transmittance for a single clear pane Ug = 5.6 $W/m^2.K.$, is reduced by adding a second clear pane to Ug=2.8 $W/m^2.K.$ Figure 13, presents the total cooling loads predicted on a typical m^2 of the base case on monthly basis. During winter, the cooling loads increased 17% than having a single clear pane this corresponds to an increase of $5W.h/m^2$.

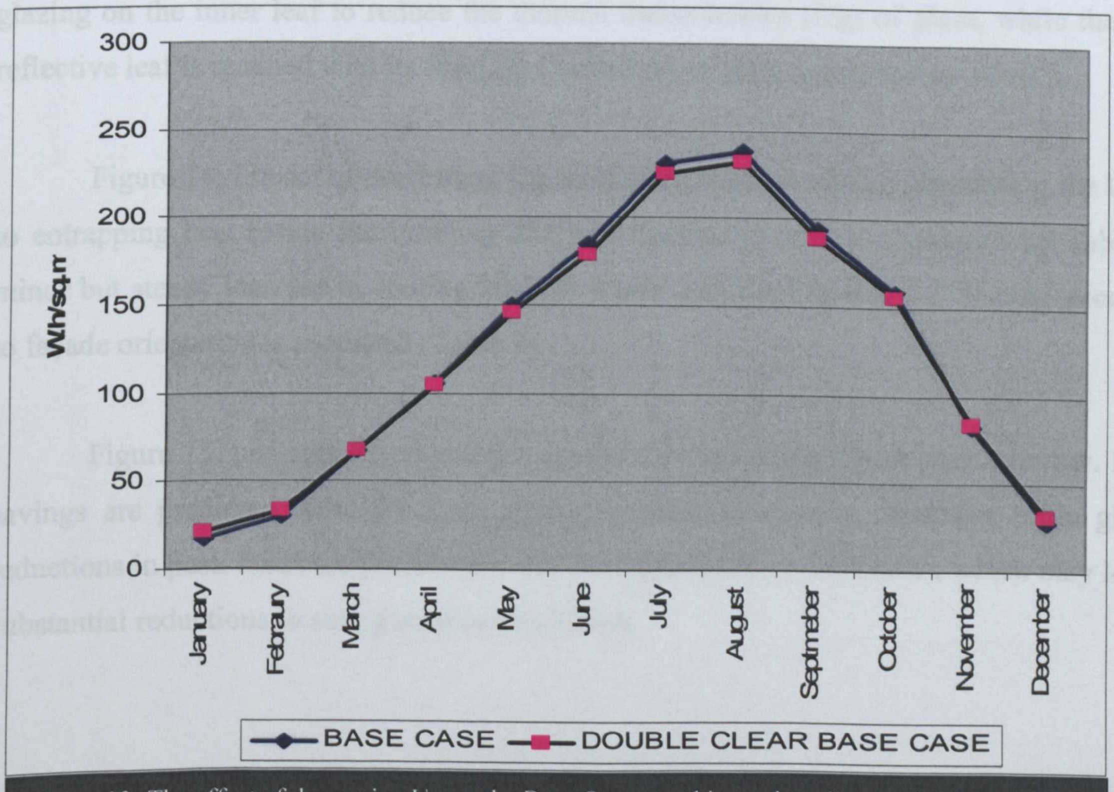


Figure 13: The effect of decreasing Ug on the Base Case monthly total cooling loads

Compared to results from adding external insulation to the base case decreasing Ug had a worse impact on increasing winter cooling loads. It is interesting to note that in between season months adding the extra glazing layer was not predicted to achieve any changes in total cooling loads.

Reductions of total cooling loads were predicted in summer month, with a peak summer total cooling load reduction of 3%. Simulation results indicate that using double clear glazing as a single cooling load refurbishment strategy does not yield significant energy savings. However, the use of double panes is recommended to reduce noise levels in urban sites. As Cairo is characterized by high noise and air pollution levels, simulations were carried out to investigate the impact of combining reductions to Ug with a low SC on total cooling loads.

The previous set of simulations in section (6.5.1.) indicated the advantage of using reflective glazing compared to body tinted glazing whenever reductions of cooling loads are required. In this section, the thermal transmittance of glazing is varied by adding clear glazing on the inner leaf to reduce the thermal transmittance (Ug) of glass, while the outer reflective leaf is retained with its Shading Coefficient of glass controlled to SC=0.5.

Figure 14: Impact of decreasing Ug on cooling loads in winter. Decreasing the Ug led to entrapping heat inside the building due to reduction in heat loss through the fabric. A minor but steady increase in cooling loads in winter ranging between 1-3 W.h/m^2 according to façade orientation is predicted (Table 2).

Figure 15, presents the simulation results for decreasing Ug in peak summer. Major savings are predicted if single clear glazing is substituted by a reflective triple glazing reductions in peak loads are predicted to be 14% equivalent to 30W.h/m^2, which may lead to substantial reductions in sizing cooling equipment.

On Annual basis, Table 4, if triple reflective glazing is compared to the Base Case then the most reductions in total cooling loads are achieved on average 17% on the East, West, and South Facades. However this conclusion is different in its significance when adding layers to the reflective glazing is compared.

The North façade indicated insignificant decreases in total cooling loads when Ug was reduced, whether using double or triple the decrease in total cooling loads was a minor 1-2%.

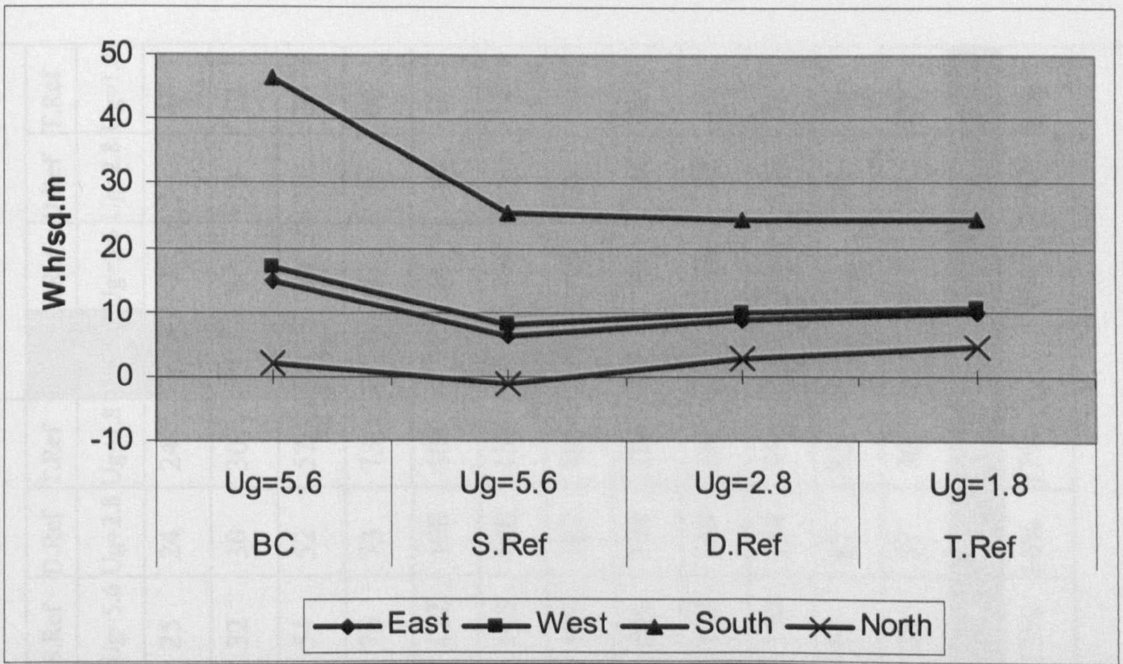


Figure 14: Impact of decreasing Ug on cooling loads in winter

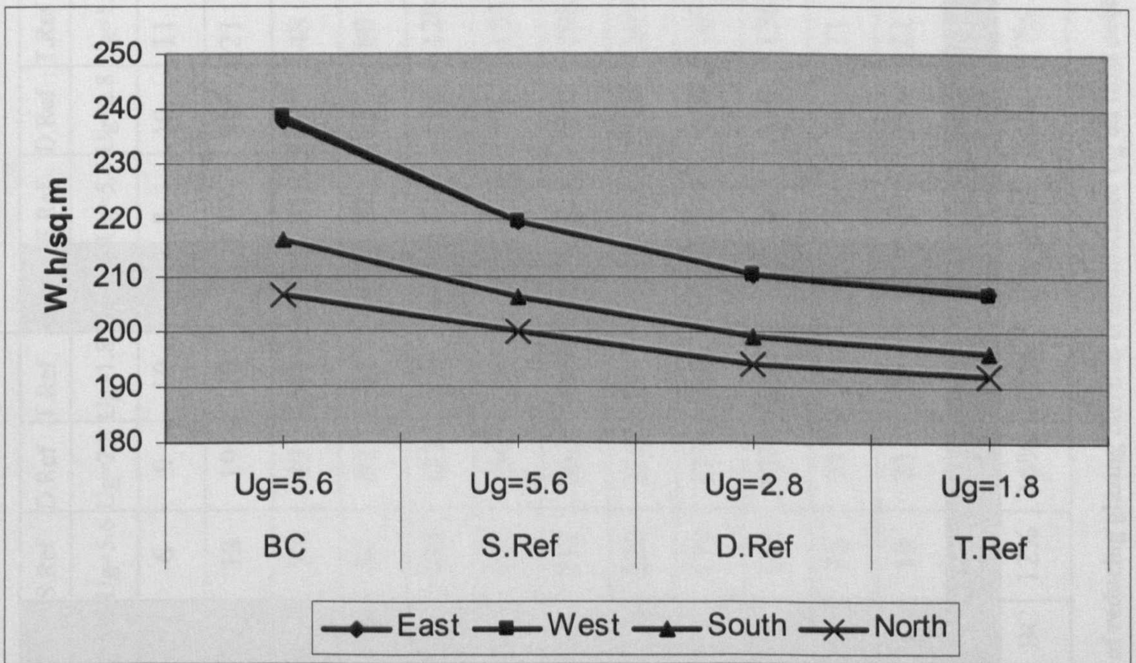


Figure 15: Impact of decreasing Ug on peak summer total cooling loads

* BC=Base Case, S.Ref= Single Reflective, D.Ref=Double reflective, inner pane clear 6mm glazing

	East				West				South				North			
	BC	S.Ref	D.Ref	T.Ref	BC	S.Ref	D.Ref	T.Ref	BC	S.Ref	D.Ref	T.Ref	BC	S.Ref	D.Ref	T.Ref
	Ug=5.6	Ug=5.6	Ug=2.8	Ug=1.8	Ug=5.6	Ug=5.6	Ug=2.8	Ug=1.8	Ug=5.6	Ug=5.6	Ug=2.8	Ug=1.8	Ug=5.6	Ug=5.6	Ug=2.8	Ug=1.8
January	15	6	9	10	17	8	10	11	47	25	24	24	2	-1	3	4
February	30	18	19	20	31	19	20	21	52	32	30	30	11	8	10	12
March	66	50	49	48	68	51	49	48	72	54	52	52	39	34	36	36
April	105	87	82	81	106	87	82	80	87	76	73	73	73	67	66	66
May	148	129	122	120	150	130	123	120	120	112	108	108	123	112	108	107
June	184	165	156	153	185	172	156	152	153	145	140	138	159	149	143	141
July	230	212	202	199	232	213	202	198	201	198	187	185	203	195	198	186
August	238	220	210	207	239	220	210	207	216	206	199	196	207	200	194	192
September	196	179	171	168	194	177	170	167	194	177	169	166	165	159	155	153
October	158	143	138	136	159	143	138	136	179	156	148	145	132	127	124	124
November	83	72	71	71	82	72	71	71	115	92	87	85	65	62	63	63
December	28	19	21	21	28	19	21	22	61	39	37	36	14	11	14	15
Total	1481	1299	1250	1234	1490	1311	1252	1232	1498	1309	1254	1238	1192	1121	1114	1099
Reduction from BC		12%	16%	17%		12%	16%	17%		13%	16%	17%		6%	7%	8%

Table 4: Impact of reducing glazing thermal transmittance Ug on total cooling loads

7.7.3 Testing the Significance of Change:

On annual basis Table 4, indicated minor decreases on the annual total cooling loads when glazing layers were increased. Compared to a single reflective glazing scenario the decrease in thermal transmittance of glazing Ug only led to 4% decrease in annual total cooling loads in the case of double reflective glazing and a further 1% when a third glazing layer was added.

Based on the previous analyzes of peak and annual total cooling loads, decreasing the thermal transmittance of glazing indicated a minor impact on reducing total cooling loads in Cairo's hot arid climate. The previous predictions lead to the conclusion that for a hot arid area improving the shading (solar rejection) properties of glazing while maintaining optimum visible light transmittance are more beneficial than decreasing the thermal transmittance of the glazing. These findings are in accord with other simulation studies on the dominating factors on windows performance in cooling load dominated buildings in the hot climates in the USA (Sullivan et al 1995).

7.8 Changing Glazing Properties During Façade Refurbishment:

The previous simulations discussed the effect of orientation, changing the thermal transmission of walls by applying thermal insulation to opaque areas, or reducing the U-value of glazed areas. Scenarios also looked at changing the resistance of glazed areas to direct solar penetration by reducing the shading coefficient of glazing. Among the three scenarios, it is evident that in hot arid areas the decrease of direct solar penetration through the glazing areas indicated the most efficient single refurbishment measure to reduce peak and annual total cooling loads. However, if a holistic scheme is intended and the economy of refurbishment is not the issue then the three scenarios maybe combined for maximum energy savings.

The previous set of base case simulations predicted that reducing the Shading Coefficient of glazing indicated the most significant savings of the cooling loads. This refurbishment scenario is taken forward to test its effect on improving the thermal performance of existing office building façade's configurations.

The Cairo office building survey indicated that for buildings in their refurbishment phase, the window to wall ratio ranged between 20-40% of the façade area. A set of simulations using heat reflective glazing were used on intervals of WWR.

Analyzing the data two directions of discussion emerged. The first being the impact of changing the glazing properties while maintaining the existing WWR. The second direction would be to look at the impact of changing the WWR and the Shading coefficient simultaneously, to look at possibilities of increasing/decreasing existing WWR and incurred changes in the cooling demands.

7.8.1 Case 4: Changing the Glazing Properties While Maintaining Existing WWR

The identification of three existing façade configurations in the Cairo office building survey till the 1970s, created three separate base cases for comparing energy saving measures (equivalent BC) .[1]

The impact of changing glazing properties on peak summer total cooling loads on existing façades are presented in Table 5: Impact of Changing SC on Existing WWR in peak summer.

[1] In this analysis, each façade configuration is treated as a base case for its equivalent energy saving measures. i.e. a façade of 40%WWR with clear glazing is the base case for a 40% WWR with reflective glazing. A 30% WWR with clear glazing is the base case for a 30% WWR with reflective glazing and so on. Whenever a cross examination of the results is carried out this is indicated in the text.

Table 5: Impact of Changing SC on Existing WWR on peak summer loads.

	CL WWR 40%	RF WWR 40%	Reductions	CL WWR 30%	RF WWR 30%	Reductions	CL WWR 20%	RF WWR 20%	Reductions
East	238	220	8%	227	213	6%	217	207	4%
West	239	220	8%	227	213	6%	217	207	5%
South	216	206	5%	210	202	4%	204	198	3%
North	207	200	3%	202	197	3%	197	194	2%

Changing the glazing performance on the 40% WWR has been presented previously in section 6.5.1. Changing the glazing properties on the 30% WWR indicate reductions of 14 W.h/m^2 on the main cooling load generating facades. However, changing the glazing properties on the 20% WWR indicated reductions of 10 W.h/m^2. In this case, maintaining existing WWR and substituting existing clear glazing with heat reflective glazing on WWR below 30% is predicted to reduce generated loads due to façade configurations and increasing the dominance of internal loads to be removed by the cooling systems. The North façade indicated minor reductions of cooling loads on all façade configurations indicating the irrelevant impact of reducing the glazing Shading Coefficient.

Table 6: Impact of changing SC on existing WWR in peak winter

	CL WWR 40%	RF WWR 40%	Reductions	CL WWR 30%	RF WWR 30%	Reductions	CL WWR 20%	RF WWR 20%	Reductions
East	15	6	43%	12	6	47%	9	5	53%
West	17	8	47%	14	7	47%	10	6	57%
South	47	25	55%	37	21	57%	28	17	61%
North	2	-1	-43%	2	-1	-51%	2	-1	-54%

Table 6, indicates that in winter, using heat reflective glazing on existing façade configurations approximately halved the total cooling loads on all East, West and South facades compared to using clear glazing.

However, reducing the WWR on the South facing façade indicated the maximum reductions in total cooling loads. Reducing the WWR ratios from 40% to 20% had a major impact on reducing cooling loads in winter month. Even if clear glazing is used (Table 10) the reduction of WWR from 40 to 20% halved the total cooling loads.

The North facing façade using heat reflective glazing on all examined WWRs indicated a minor heating load requirement that can be ignored $1W/m^2$. It is important to note that reducing total cooling loads in winter by using reflective glazing on various façade configurations on the North oriented façade is found to be independent of the WWR. This creates less constraint on the window size on this façade orientation.

WWR ratios of 20% are also found in older and listed buildings of the existing office stock, using reflective glazing may raise concerns of alterations to the aesthatic appearance of the building especially if the building has a historic value. However, advances in glazing technology promise heat reflective glazing will a less reflective appearances.

The use of reflective glazing on WWR below 30% must also be balanced with requirements for daylighting. As discussed in chapter two the severe reductions in daylighting levels –especially amenity daylighting- has psychological impacts and reduces workplace performances.

Table 7: Impact of changing SC on existing WWR on annual total cooling loads

	CL WWR 40%	RF WWR 40%	Reductions	CL WWR 30%	RF WWR 30%	Reductions	CL WWR 20%	RF WWR 20%	Reductions
East	1480	1299	12%	1387	1250	10%	1301	1208	7%
West	1490	1311	12%	1391	1250	10%	1299	1203	7%
South	1498	1309	13%	1398	1255	10%	1308	1210	7%
North	1192	1121	6%	1153	1101	5%	1121	1083	3%

Analysing the annual total cooling loads in (Table 7), substituting clear glazing on exsisting facades indicated major reductions on all three WWR examined. The total cooling loads reductions are more pronounced in larger WWR as the heat reflecive properties of the glass reduces the transmission of direct solar radiation. It is concluded that the relation between reducing the direct solar transmission is directly proprtional to the WWR.

Analyzing monthly loads of East, West and South façade orientations (Table 8, Table 9 and Table 10) indicated that using reflective glazing reduced the cooling loads on all façade orientations year round.

The North façade indicates minor savings in comprision with the other three orientatios when WWR are reduced.

However, analysing the data cross-sectionally, there is an indication that the smaller the WWR the smaller the impact of the façade on the cooling load, and therefore the smaller the savings from retrofitting with energy saving measures to the glazed areas.

Table 8: Impact of changing SC and WWR on monthly total cooling loads (East Orientation)

EAST ORIENTATION (total cooling load in W.h/m^2)						
	CL WWR 40%	CL WWR 30%	CL WWR 20%	RF WWR 40%	RF WWR 30%	RF WWR 20%
January	15	12	9	6	6	5
February	30	25	21	18	16	15
March	66	59	52	50	47	44
April	105	96	87	87	82	78
May	148	138	128	129	124	119
June	184	173	163	165	159	153
July	230	220	209	212	205	200
August	238	227	217	220	213	207
September	196	186	177	179	173	168
October	158	150	142	143	139	135
November	83	78	74	72	70	68
December	28	24	21	19	18	17
Total	1480	1387	1301	1299	1250	1208

Table 9: Impact of changing SC and WWR on monthly total cooling loads (West Orientation)

WEST ORIENTATION (total cooling load in W.h/m^2)						
	CL WWR 40%	CL WWR 30%	CL WWR 20%	RF WWR 40%	RF WWR 30%	RF WWR 20%
January	17	14	10	8	7	6
February	31	26	21	19	17	15
March	68	59	52	51	47	44
April	106	96	87	87	81	77
May	150	139	129	130	124	118
June	185	173	162	172	158	152
July	232	220	209	213	205	199
August	239	227	217	220	213	207
September	194	184	175	177	171	166
October	159	150	142	143	139	134
November	82	77	73	72	70	68
December	28	26	22	19	18	17
	1490	1391	1299	1311	1250	1203

Table 10: Impact of changing SC and WWR on monthly total cooling loads (South Orientation)

SOUTH ORIENTATION (total cooling load in W.h/m^2)

	CL WWR 40%	CL WWR 30%	CL WWR 20%	RF WWR 40%	RF WWR 30%	RF WWR 20%
January	47	37	28	25	21	17
February	52	43	34	32	28	24
March	72	64	56	54	50	47
April	87	81	76	76	73	70
May	120	115	111	112	109	107
June	153	148	143	145	142	139
July	201	195	191	193	190	187
August	216	210	204	206	202	198
September	194	184	176	177	172	167
October	179	167	155	156	149	143
November	115	103	93	92	86	81
December	61	51	41	39	34	30
	1498	1398	1308	1309	1255	1210

Table 11: Impact of changing SC and WWR on monthly total cooling loads (North orientation)

NORTH ORIENTATION (total cooling load in W.h/m^2)						
	CL WWR 40%	CL WWR 30%	CL WWR 20%	RF WWR 40%	RF WWR 30%	RF WWR 20%
January	2	2	2	-1	-1	-1
February	11	10	10	8	8	8
March	39	37	36	34	33	33
April	73	70	67	67	65	64
May	123	115	111	112	109	107
June	159	153	147	149	145	142
July	203	197	192	195	191	188
August	207	202	197	200	197	194
September	165	161	157	159	156	154
October	132	129	126	127	125	123
November	65	64	63	62	61	61
December	14	13	13	11	11	11
	1192	1153	1121	1121	1101	1083

7.8.2 Case 5: Changing the Window to Wall Ratio and the Shading Coefficient on Existing Facades:

Observing vernacular residential architecture, WWR were always reduced to a minimum for providing ventilation and a view out, especially exposed to solar radiation facades. Further research on hot arid areas (Givoni 1976; Givoni 1998; Lam and Hui 1996) asserted that reducing the WWR is the most effective measure to reduce cooling loads in hot arid areas. However, in the context where the office building enjoys a panoramic view out, it would not be practical to recommend reduction of current WWR for energy saving purposes, as this would radically reduce the property market value. On the contrary increasing the glazed area on facades maybe required especially whenever a beautiful view out is available, or as a projection of wealth and prosperity on facades. Advances in glazing technology claim the possibility of increasing glazed areas without energy penalties, while controlling quality and quantity of daylight. It is the objective of the data analysis to quantitatively predict to what extend increasing the WWR can be achieved without increasing the peak summer and annual total cooling loads.

Figure 16, Figure 17, and Figure 18, indicate the results of using reflective glazing on all façade orientations. The X axis presents simulation results for 20-30-40 WWR, while the Y axis presents cooling loads per m^2. If no measures to reduce direct solar penetration are followed, increasing the WWR on all facades indicated excessive solar heat gain. The increase in associated solar gains causes an increase in cooling loads. Comparing these results, using clear glazing on facades, there is a directly proportional relation between reducing the Shading Coefficient on each façade configuration and reducing cooling loads in all façade orientations. A 20%WWR façade with clear glazing required a cooling load similar to a 40% WWR using reflective glazing. This result indicated the possibility of increasing glazed areas in smaller WWR original facades without a heavy energy penalty. However if reductions of the cooling loads are required it can be seen that all simulations indicated that reducing the WWR and using lower Shading Coefficients provided the most substantial reductions in total cooling loads. In Winter combining both reductions of WWR and SC of a 40% WWR with clear glazing to 20% WWR with reflective glazing is predicted to decrease winter peak loads by about $10W/m^2$ on East and West facades, and by about $30W/\ m^2$ in peak summer month. On annual basis the combined effect of using reflective glazing and reducing the WWR from 40% to 20% indicates a reduction of about $270W/\ m^2$ which is about 20% of the annual cooling loads

However, analyzing Figure 16 and Figure 17, A cross-sectional examination of results indicate that if clear glazing is to be maintained then reducing the WWR is effective in reducing cooling loads. While in cases where reflective glazing is used reducing the WWR is less beneficial on reducing cooling loads. This is clearly indicated by the slope of the results line in the graph.

The annual reduction in total cooling loads indicated that a smaller WWR and a higher SC are the best strategies to reduce cooling loads for Single Skin office building facades in hot arid areas (Figure 18). This directly proportional relation between decreasing the WWR and the higher SC on decreasing annual cooling loads has also been reported by simulation of an office building in a similar hot arid weather profile in Blyth California (USA). The glazing remains the weakest point to thermal transfer in facades. The linear relationship between increasing WWR and increasing total cooling loads still exists but is reduced in impact by using reflective glazing (Sullivan et al. 1995).

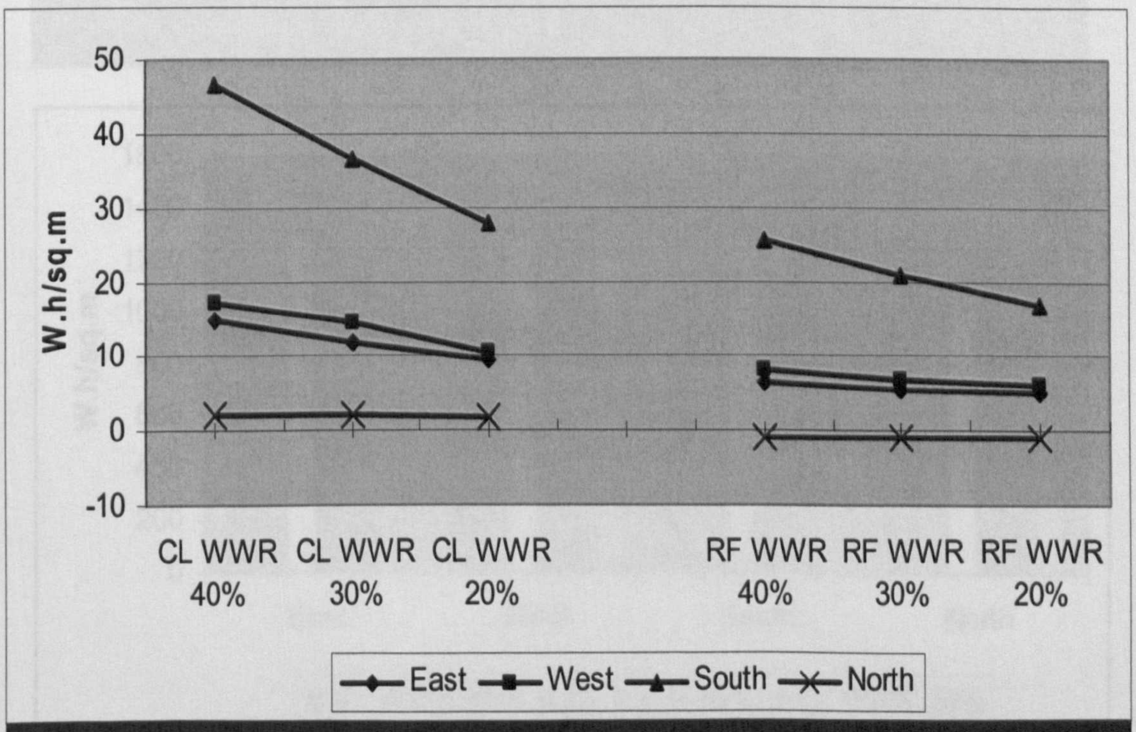


Figure 16: Impact of using reflective glazing on winter loads on existing facade configurations

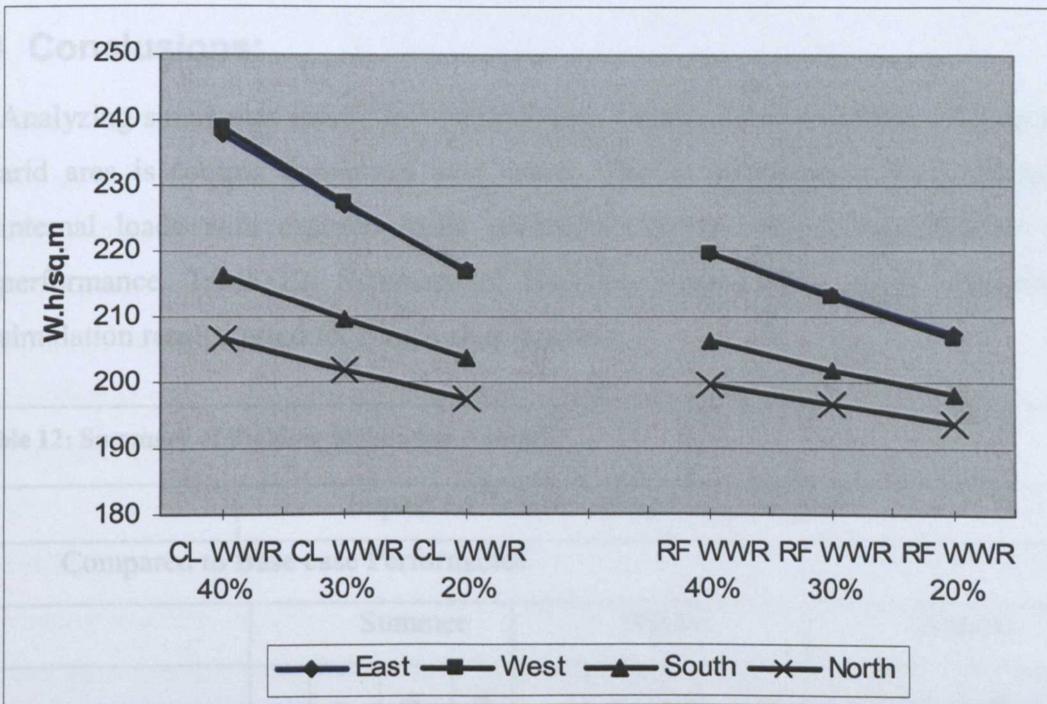


Figure 17: Impact using reflective glazing on peak summer cooling loads on existing facades

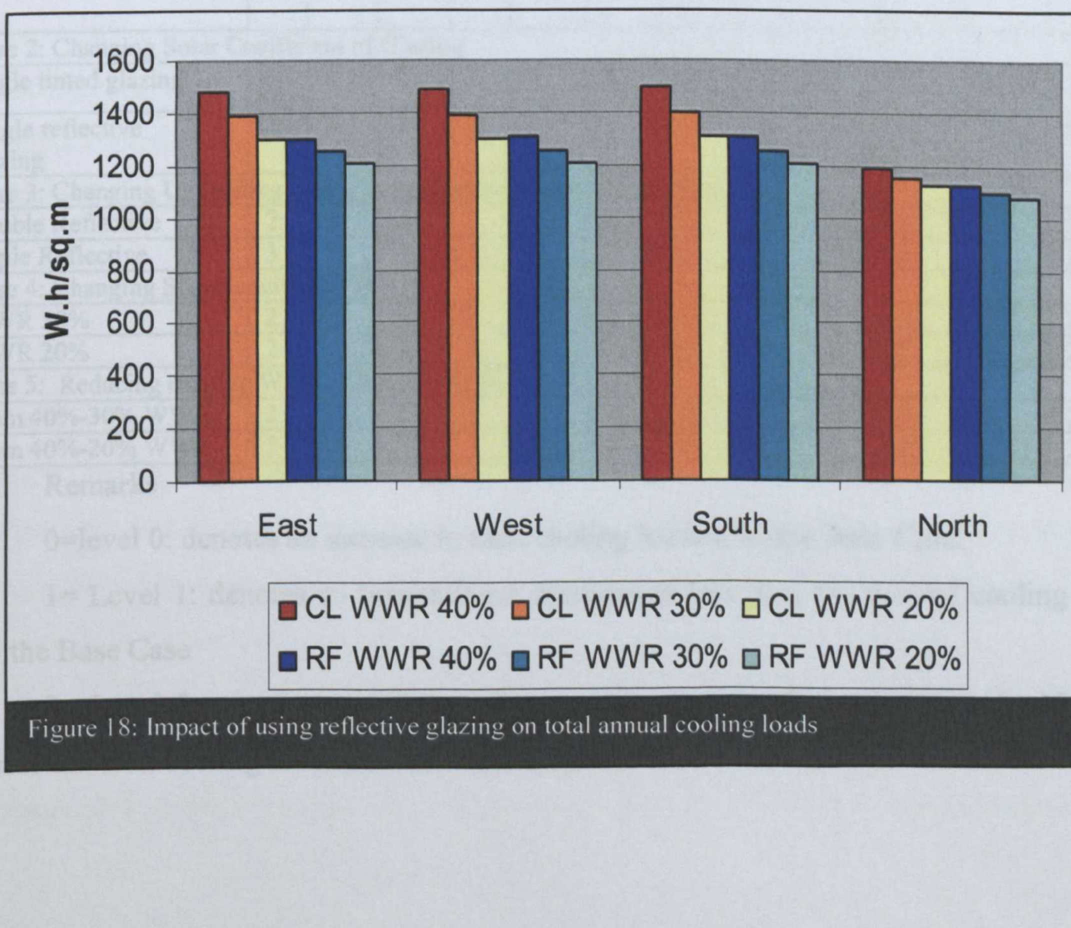


Figure 18: Impact of using reflective glazing on total annual cooling loads

7.9 Conclusions:

1. Analyzing simulation results for the base case indicated that an office building in a hot arid area is cooling dominated year round. This is attributed to the combination of internal loads with external loads generated due to the building façade's thermal performance. Table 12: Summary of Building Simulation Analysis summarizes all simulation results tested for Single skin facades.

Table 12: Summary of Building Simulation Analysis

	Impact on Total Cooling Loads W.h/m² Compared to Base case Performance											
	Summer				Winter				Annual			
	East	West	South	North	East	West	South	North	East	West	South	North
Case 1: Changing U_0	1	1	1	1	0	0	0	0	1	1	1	0
Case 2: Changing Solar Coefficient of Glazing												
Single tinted glazing	1	1	1	1	2	2	2	2	2	2	2	1
Single reflective glazing	2	2	2	2	2	2	2	2	2	2	2	2
Case 3: Changing Ug (adding clear glazing layers to reflective glazing)												
Double Reflective	2	2	2	2	2	2	2	2	2	2	2	2
Triple Reflective	3	3	3	3	3	3	3	3	3	3	3	3
Case 4: Changing SC on equivalent WWR												
WWR 30%	2	2	2	2	2	2	2	2	2	2	2	2
WWR 20%	2	2	2	2	2	2	2	2	2	2	2	2
Case 5: Reducing existing WWR and reducing SC												
From 40%-30% WWR	2	2	2	2	2	2	2	2	2	2	2	2
From 40%-20% WWR	3	3	3	3	3	3	3	3	3	3	3	3

Remarks

0=level 0: denotes an increase in total cooling loads than the Base Case.

1= Level 1: denotes an insignificant decrease of less than 5% in total cooling loads than the Base Case

2= Level 2: An energy efficient single skin façade configuration that significantly reduces the total cooling loads than the Base Case

3= Level 3: denotes a façade configuration with the least impact on cooling loads.

2. Table 12, indicates that the façade's orientation plays a major role in determining the impact of the façade configuration on the internal zones. Although peak summer calculations are generally used to size cooling and heating equipment, analyzing simulations results indicated different conclusions that may be drawn if only peak summer, were studied. A holistic method was used to analyze the results. This included analysis of peak summer month, peak winter month and the annual performance for each proposed energy saving measure.

3. Testing hypothesis one : *'With no alterations to the architectural configurations of existing facades, reducing conduction gains through the opaque areas for a single skin configuration will reduce the cooling and heating loads'*, This was studied by examining the effect of using external thermal insulation on the base case (Case 1). Reducing the conduction gains through the opaque façade areas indicated minor impacts on reducing the total cooling loads. This indicated that the transparent areas in the façade configurations are the major contributors to the cooling loads. This led to testing the impact of reducing radiation and conduction gains through the transparent façade areas of the base case.

4. Case 2, looked at testing hypothesis two: *'With no alterations to the architectural configurations reducing radiation gains through the transparent façade area will reduce cooling and heating loads.'* The second group of simulations looked at changing the visual performance of glazed area on the base case. This is studied by decreasing the direct solar transmission through reducing the Glazing Shading Coefficient on the base case. When compared to body tinted and clear glazing, heat reflective glazing was found superior in its performance towards reducing total cooling loads year round.

5. Hypothesis three states; *'With no alterations to the architectural configurations reducing conductive gains through the transparent façade area will not significantly reduce*

cooling and heating loads'. The thermal transmittance of clear glass was decreased by adding layers of clear glazing layer thus reducing the Ug-value. Simulation results indicated decreasing the Ug led to a minor increase in total cooling loads, while in summer a minor decrease in total cooling loads was predicted. Thus concluding that decreasing the thermal transmittance of glazing as a single refurbishment energy saving measure for office buildings in a hot arid climate may not be appropriate from a thermal performance point of analysis.

Case 3, Combined the effect of reducing direct solar transmission to reducing conduction gains of the transparent areas was examined. This was achieved by adding clear glazing layers internally to the exterior reflective glazing. The above analysis indicates that refurbishing single clear windows with reflective triple glazed windows achieved the highest reductions on cooling loads.

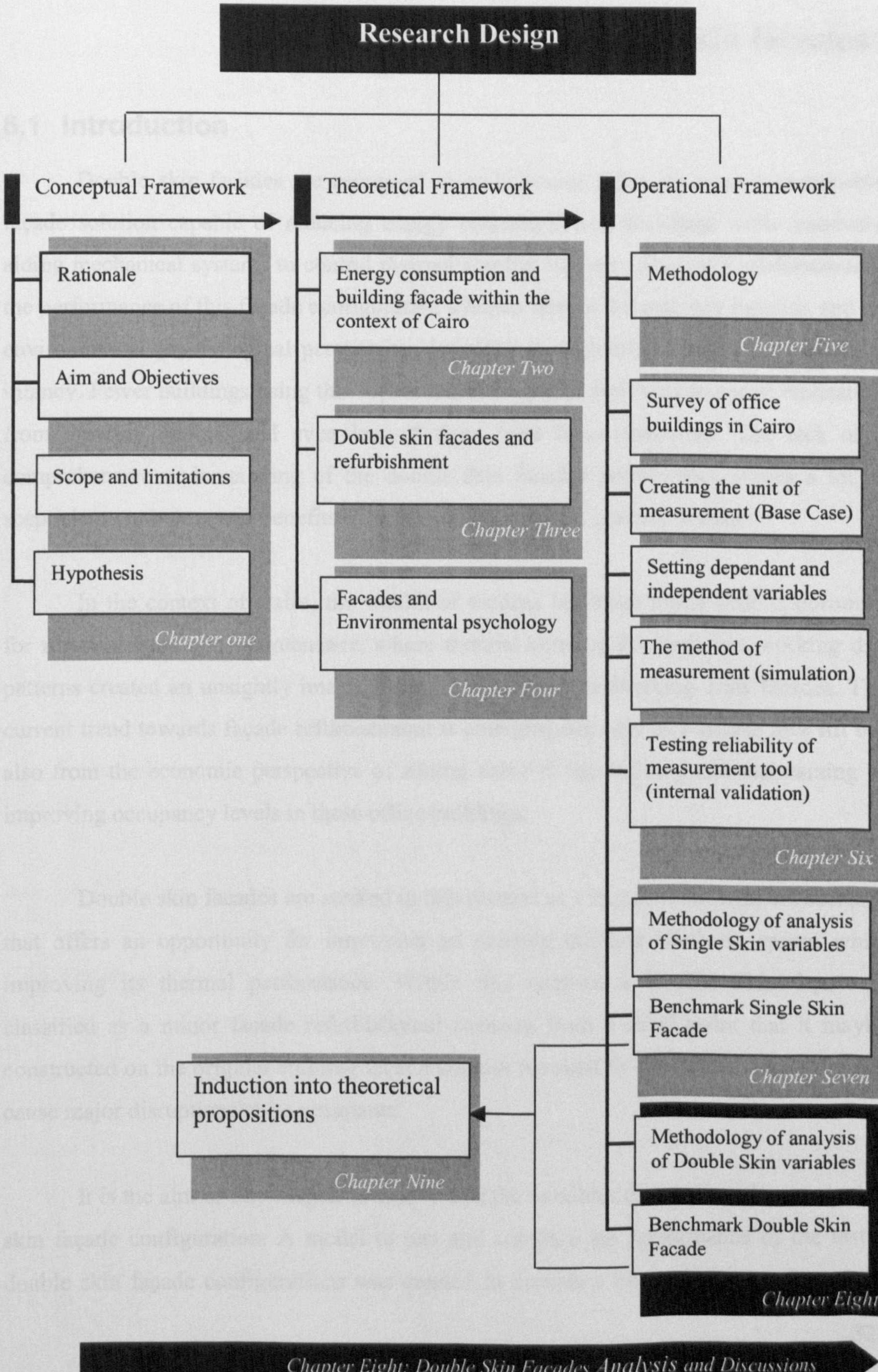
6. The previous simulations inclusively indicate that reducing the conduction gains through the single skin facades whether by adding additional glazing layers to the glazed areas or by adding insulation to the opaque areas did not indicate major cooling load reductions. This indicates that in a hot arid climate, compared to radiation gains, conduction gains are minor loads to be removed by the building cooling systems
7. The results of (Case 3) were then compared to the performance of a single reflective glazing (Case2) to test the significance of reducing the glazing U-value. As reductions were insignificant and triple glazing is expensive Case 2 was chosen as a Benchmark single skin for further comparisons in Chapter 7. Testing the significance of cooling load reductions between scenarios indicated that for a façade with a large WWR (40%), and where reductions to the WWR are not possible then an un-insulated brick wall with heat reflective glazing for its transparent areas indicated the optimum reductions in total cooling loads. This scenario will be used in further comparisons with double skin façade configurations. It will be referred to within the text as 'Benchmark Single Skin.'

8. Testing Hypothesis four: 'Major Alterations to the architectural façade configurations by reducing Window to Wall Ratios (WWR), and the Shading Coefficient (SC), will significantly decrease heating and cooling loads'. The substitution of clear glazing by a

single reflective glazing for all orientations was generally predicted to lead to major total cooling load reductions on the various WWR tested (Case 4). Case 5, indicated that if WWR and the Shading Coefficient are reduced simultaneously the reductions in total cooling loads equate a 40% WWR with triple reflective glazing. Simulations indicated that reducing the WWR on existing facades still offered the most significant total cooling energy load reductions. However it is argued that the use of glass in office building facades has a symbolic and psychological effect that may dominate over any reasoning for reducing existing glazed areas. On the contrary especially in areas with a good view out increasing the WWR maybe required regardless of energy penalties on the building systems. This set of simulations indicated the benefits from reducing the WWR while using clear glazing maybe offset by replacing the existing clear glazing with reflective glazing and without decreasing the WWR. If an increase in WWR is required then using reflective glazing is predicted to minimize the possible increase in cooling loads due to its ability to decrease the transmission of direct solar radiation indoors.

Chapter Eight: Double Skin

Key Concepts



Research Design
Conceptual Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Theoretical Framework
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Operational Framework
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
The method of measurement (simulation)
Testing reliability of measurement tool (internal validation)
Chapter Six
Methodology of analysis of Single Skin variables
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Methodology of analysis of Double Skin variables
Benchmark Double Skin Facade
Chapter Eight
Induction into theoretical propositions
Chapter Nine
Chapter Eight: Double Skin Facades Analysis and Discussions

8 Chapter Eight: Double skin facades:

8.1 Introduction

Double skin facades are promoted in architectural publications as a sustainable façade solution capable of reducing energy consumption in buildings while passively aiding mechanical systems to control thermal comfort indoors. However, understanding the performance of this façade configuration whether from a thermal, day lighting, and an environmental psychological perspective, let alone its economic viability is still in its infancy. Fewer buildings using this façade technology find their way to actual realization from drawing boards, and even less of them have been monitored. The lack of a comprehensive understanding of the double skin facades performance leaves a lot of scepticism on their actual benefits in both the academic and practice arenas.

In the context of Cairo, the wealth of modern buildings found little opportunity for refurbishment and maintenance, where thermal comfort demands and working day patterns created an unsightly image of perforated by air conditioning units facades. The current trend towards façade refurbishment is emerging not only as a façade face lift but also from the economic perspective of adding value to the building and maintaining or improving occupancy levels in these office buildings.

Double skin facades are studied in this context as a façade refurbishment scenario that offers an opportunity for improving an existing building aesthetic appeal while improving its thermal performance. Within this context, a Double Skin façade is classified as a minor façade refurbishment scenario from a stand point that it maybe constructed on the original building façade without the need to evacuate the building and cause major disruptions to its occupants.

It is the aim of this chapter to find within the variables tested a benchmark double skin façade configuration. A model to test and compare the performance of the tested double skin façade configurations was created to provide a better understanding of the performance of this façade configuration compared to both a worse façade configuration (BC) and a benchmark single skin (BSS).

The previous chapter indicated that for refurbishing an existing office building with heavy wall mass the benchmark single skin scenario was to replace existing clear glazing panes with a single reflective glazing layer on the base case and with no insulation on the opaque areas. This refurbishment scenario of the Base Case indicated a balanced reduction on cooling loads year round. This configuration will be referred to within the text and analysis as Benchmark Single Skin *'BSS'*

8.2 Operational model for testing variables:

To Test the variables that affect the thermal performance of double skin façade configuration four main variables were identified, the thermal transmittance of the opaque, the thermal transmittance of the transparent areas (glazing), the radiant transmittance of glazing, and the Window to Wall Ratio of the façade (WWR). The first three variables are tested to find out a Benchmark double skin façade performance. The WWR is then used to test the generalizability of the benchmark double skin to other existing façade configurations indicated from the Cairo office building survey (chapter Six). Figure 1 outlines the methodology used to test variables.

To find a benchmark single skin façade, three levels of testing have been identified.

Level 0 indicates that the variables tested have led to an increase in total cooling loads than the Base Case.

Level 1 indicates that the variables tested have indicated that the façade configuration being tested led to insignificant reductions in total cooling loads than the Base Case, i.e. that reductions achieved were < 5%.

Level 2 indicates that significant load reductions have been achieved due to the variables tested. Level 3 indicates that among the façade configurations tested leading to significant changes, this particular façade configuration leads to the least total cooling loads. Level 2 and 3 collectively lead to significant reductions in total cooling loads.

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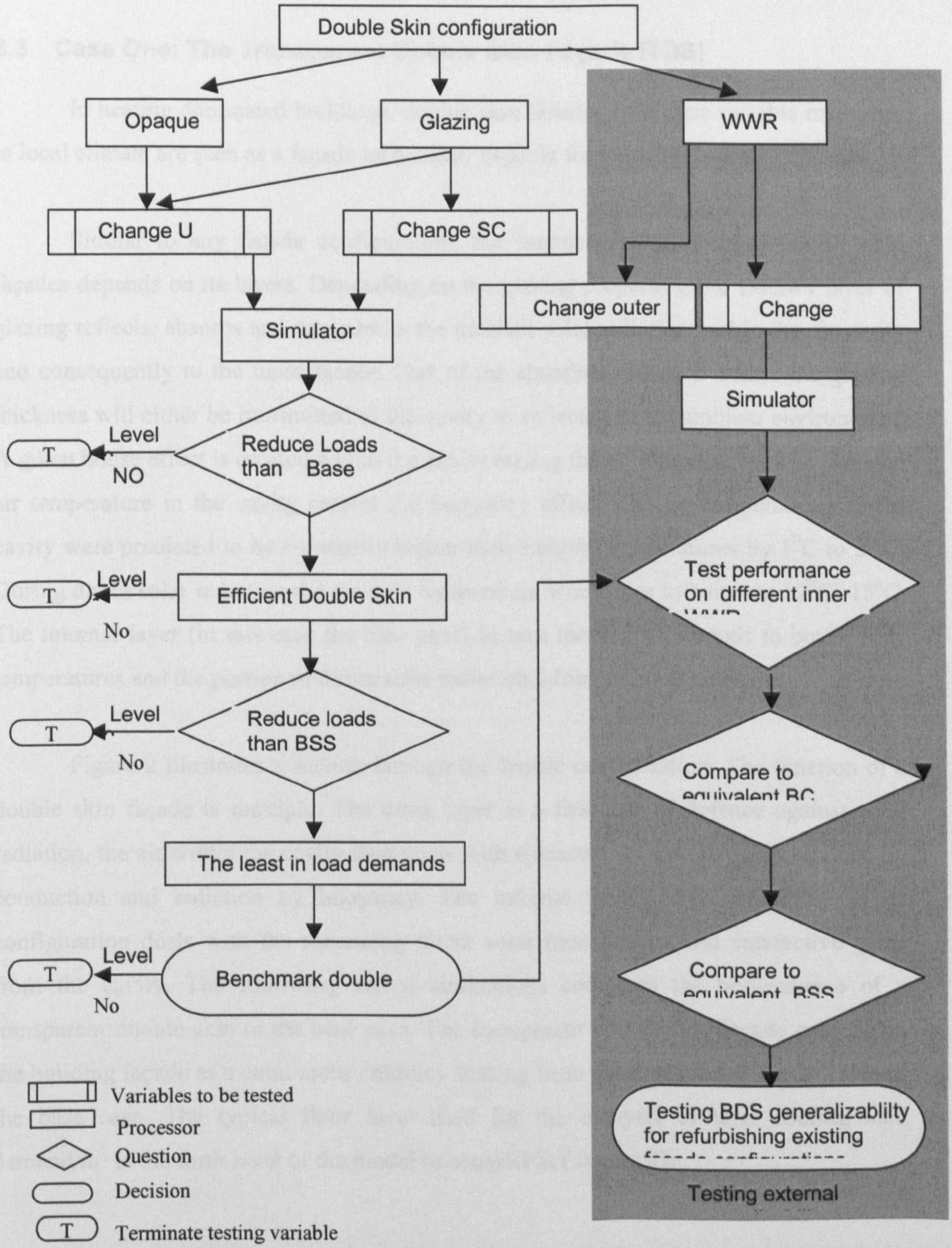

Figure 1: Operational framework to test variables affecting the thermal performance of Double Skin facades.

8.3 Case One: The Transparent Double Skin Façade (TDS)

In heating dominated buildings, double skin facades with their variable responses to local climate are seen as a façade technology capable for reducing heating demands.

Similar to any façade configuration, the thermal performance of double skin façades depends on its layers. Depending on the glazing properties, the exterior layer of glazing reflects, absorbs and retransmits the incident solar radiation within the air cavity and consequently to the inner facade. Part of the absorbed radiation within the glazing thickness will either be transmitted to the cavity or reflected to the ambient environment. A green house effect is created within the cavity raising the air temperature. The elevated air temperature in the cavity creates the buoyancy effect. The air temperatures in the cavity were predicted to be constantly higher than ambient temperatures by 1^0C to 2 ^{0}C. During direct solar radiation the cavity's temperature would rise to between 12^0C -15°C. The internal layer (in this case the base case) in turn thermally responds to both cavity temperatures and the portion of direct solar radiation falling on its surface.

Figure 2 illustrates a section through the façade configuration. The function of a double skin façade is multiple. The outer layer is a first line of defence against solar radiation, the air within the cavity then deals with extraction of excessive heat gained by conduction and radiation by buoyancy. The internal façade layer according to its configuration deals with the remaining direct solar transmission and conductive gains from the cavity. The following set of simulations compares the performance of a transparent double skin to the base case. The transparent double skin façade extends on the building façade as a continuous chimney starting from the first level to the 7^{th} level of the base case. The typical floor level used for the analysis of total cooling load demand/m^2 is the forth level of the model (discussed in Chapter 4).

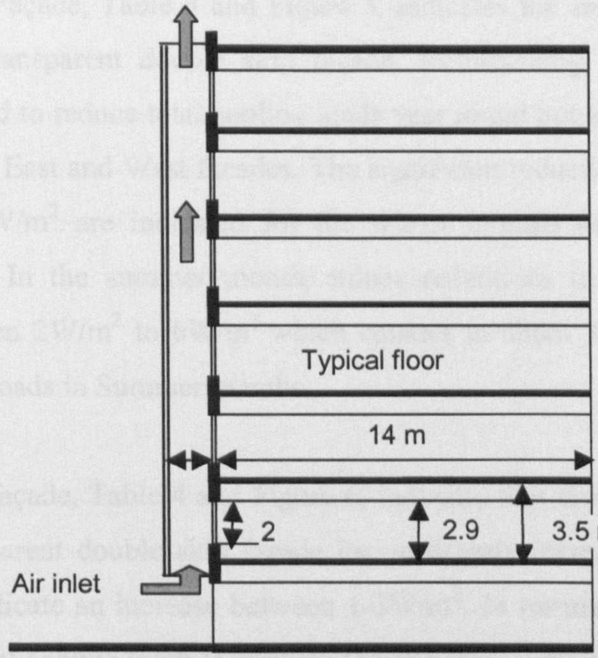

Figure 2: Schematic section through Double skin facade

For the East and West orientation, all simulation results predict that using a transparent double skin façade reduces total cooling loads year round. Table 1, Figure3, Table 2, and Figure 4 present simulation results, the transparent double skin façade reduces the total cooling loads between the months of March till October on East and West orientations more effectively than during the Winter month between November till February.

During winter months, for the East and West orientation refurbishing with a transparent double skin façade indicated minor reductions on total cooling loads -between $1W/m^2$ to $4W/m^2$ – compared to the base case with its single façade with clear glazing (no solar protection). This effect maybe attributed to the increased insulation double skin facades provides for the interior spaces, which increases conduction gains to the interior thus offsetting reductions of direct solar penetration indoors. The higher than ambient temperatures in the cavity are expected to decrease the heat loss from inner spaces.

For the South Façade, Table 3 and Figure 5, indicates the simulation results for refurbishing with a transparent double skin façade. Refurbishing with a transparent double skin is predicted to reduce total cooling loads year round but in a reversed way to its performance on the East and West facades. The significant reductions to total cooling loads between 10-20W/m^2 are indicated for the winter months between the months November to March. In the summer month, minor reductions to cooling loads are predicted to be between 2W/m^2 to 6W/m^2 which equates to about 3% reduction of the monthly total cooling loads in Summer months.

For the North façade, Table 4 and Figure 6, indicates that during the peak winter months using a transparent double skin façade insignificantly increased cooling loads. Simulations results indicate an increase between 1-3W/m^2. In summer months a similar impact on reducing total cooling loads is predicted on the other three orientations.

From the above analysis, it can be concluded that the performance of the transparent double skin façade is closely related to the duration of direct solar radiation on each façade orientation. This indicates that using double skin facades as a radiation barrier is effective on all façade orientations. Although the use of a transparent double skin façade is predicted to increase façade insulation by surrounding the building by a warm air cushion, which in hot arid area is predicted to impede heat loss from indoors to the ambient environment, but the reductions of direct solar penetration indoors is more beneficial to reducing total cooling loads.

In Winter, decreasing heat loss is desirable in heating dominated climates. In a hot arid climate, winter day temperatures are slightly below comfort temperatures. In winter months, apart from the times when direct solar radiation is incident on the façade configurations, the slightly elevated temperatures in the cavity are found to be within comfort temperatures between 20^{0}C-24 ^{0}C. Natural ventilation maybe introduced in winter even on higher floor levels. Introduction of natural ventilation in winter is a desirable energy conserving measure, but is outside the scope of this thesis.

Table 5 and Figure 7, illustrate the effect of using transparent double skin facades across the four façade orientations during the peak Winter month. The most significant reduction is on the South façade as the double skin intercepts more direct solar radiation thus its effect on the cooling load is more pronounced. The North orientation exhibits increases in cooling loads.

Table 6 and Figure 8, illustrates the effect of using transparent double skin facades across the four façade orientations during the peak Summer month. Reductions are observed on all façade orientations The North orientation exhibits increases in cooling loads.

Comparing the annual results for total cooling loads of all facades Table 8 indicates overall reductions in total cooling loads. Using a transparent double skin façade is predicted to reduce annual total cooling loads on all facades between 50-80 W/m^2, however this reduction is similar to reductions predicted for replacing clear glazing on the single skin façade by tinted glazing. In this case, it may be argued that using a transparent double skin façade leads to a transparent visual contact between indoors and outdoors while tinted glazing produces a darker image to the outside. Using a transparent double skin façade as a refurbishment option is applicable with minimum disruptions to building occupants.

Table 1: Comparison between BC and TDS on the East orientation.

EAST ORIENTATION (total cooling load in W.h/m^2)		
	BC	DS CL100%+BC
January	15	14
February	30	28
March	66	63
April	105	98
May	148	138
June	184	173
July	230	219
August	238	229
September	196	186
October	158	150
November	83	79
December	28	26
Total	1480	1401

BC=Base case
TDS= DS CL100%+BC= Clear glazing double skin façade with the Base case façade as the internal façade configuration

Table 2 : Comparison between BC and TDS on the West orientation

WEST ORIENTATION (total cooling load in W.h/ m^2)		
	BC	DS CL100%+BC
January	17	14
February	31	29
March	68	64
April	106	100
May	150	142
June	185	176
July	232	219
August	239	230
September	194	185
October	159	152
November	82	76
December	28	26
Total	1490	1413

Table 3: Comparison between BC and TDS on the South orientation

SOUTH ORIENTATION (total cooling load in W.h/ m²)		
	BC	DS CL100%+BC
January	47	40
February	52	46
March	72	68
April	87	84
May	120	116
June	153	144
July	201	193
August	216	213
September	194	186
October	179	168
November	115	104
December	61	55
Total	1498	1417

Table 4: Comparison between BC and TDS on the North orientation

NORTH ORIENTATION (total cooling load in W.h/ m²)		
	BC	DS CL100%+BC
January	2	5
February	11	13
March	39	38
April	73	71
May	123	113
June	159	149
July	203	193
August	207	199
September	165	157
October	132	126
November	65	63
December	14	15
Total	1192	1141

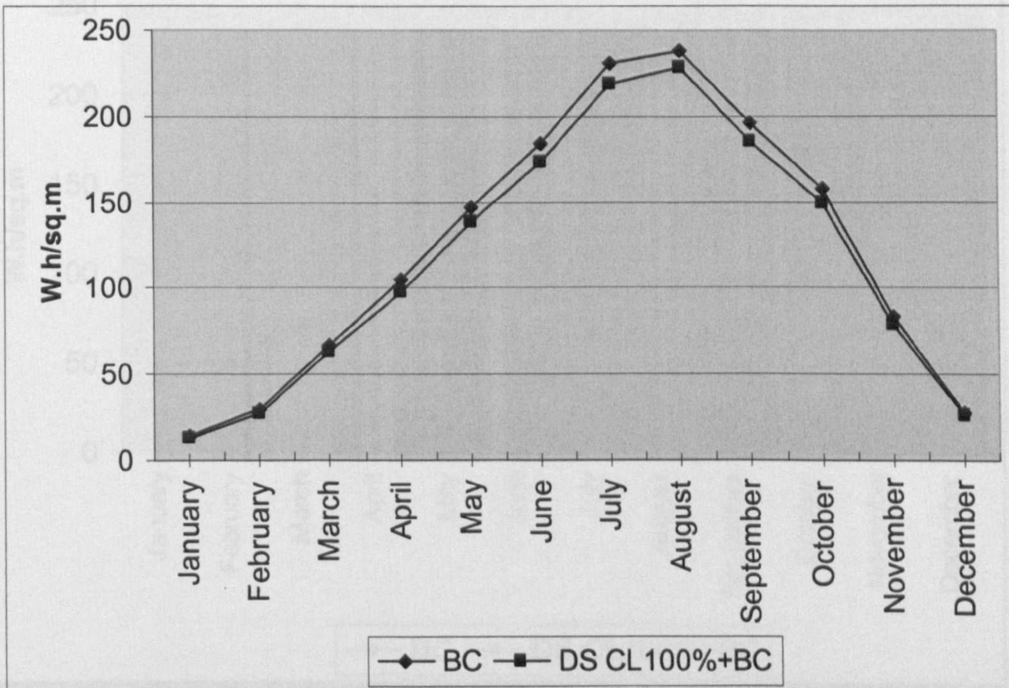

Figure 3: Transparent Double skin Facade on the East Orientation

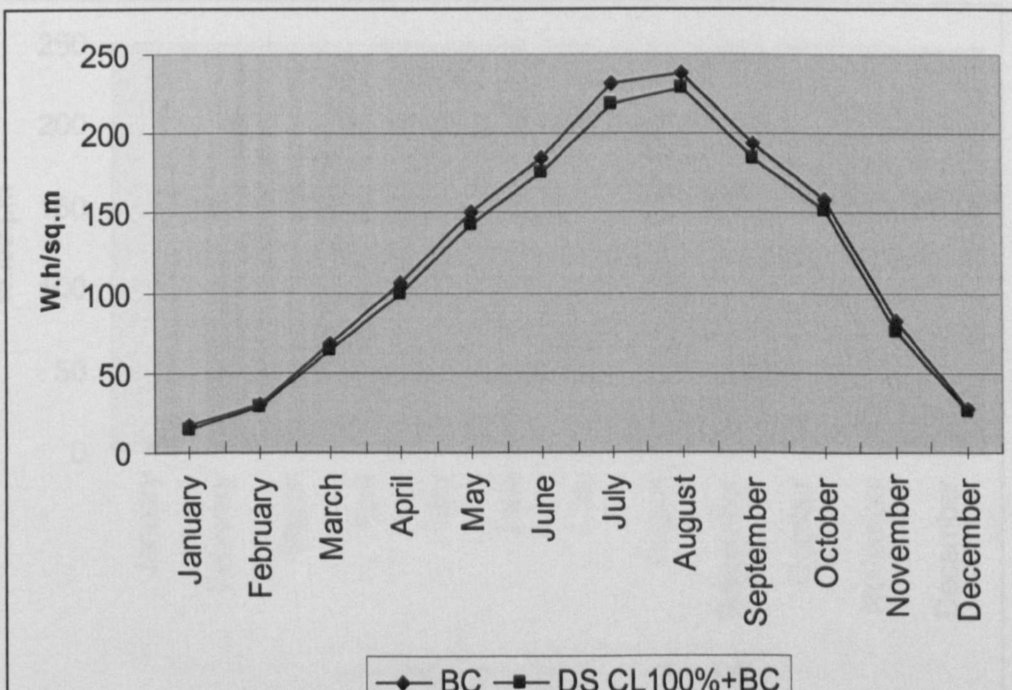

Figure 4: Impact of Transparent Double Skin Façade on the West Orientation on total cooling loads

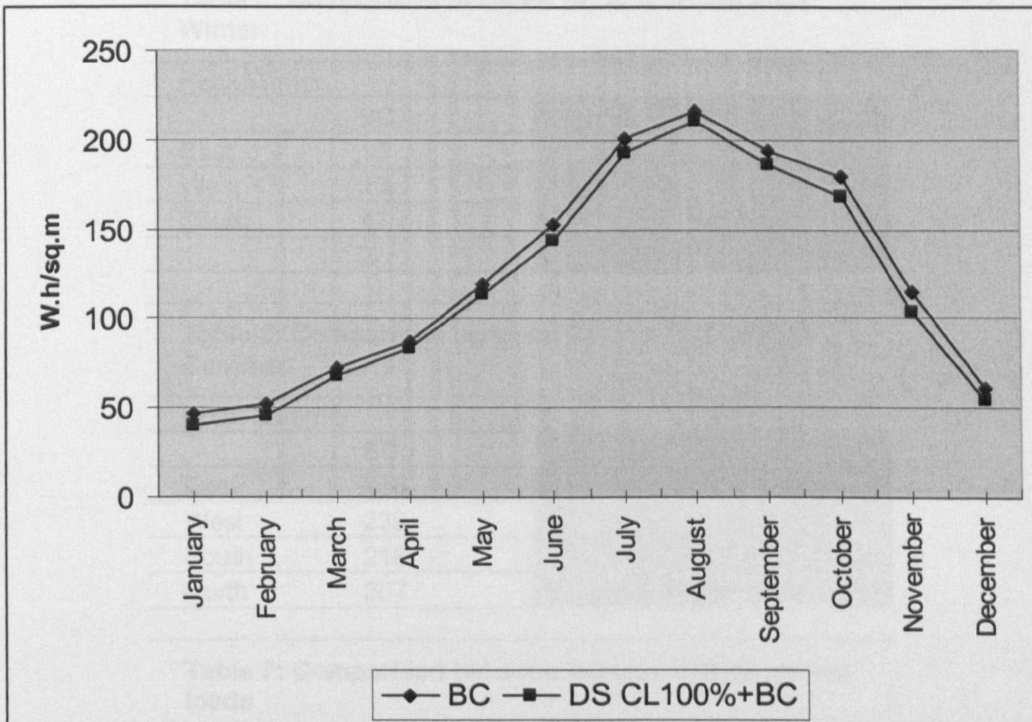

Figure 5: Impact of Transparent Double Skin Facade on South Orientation on total cooling loads

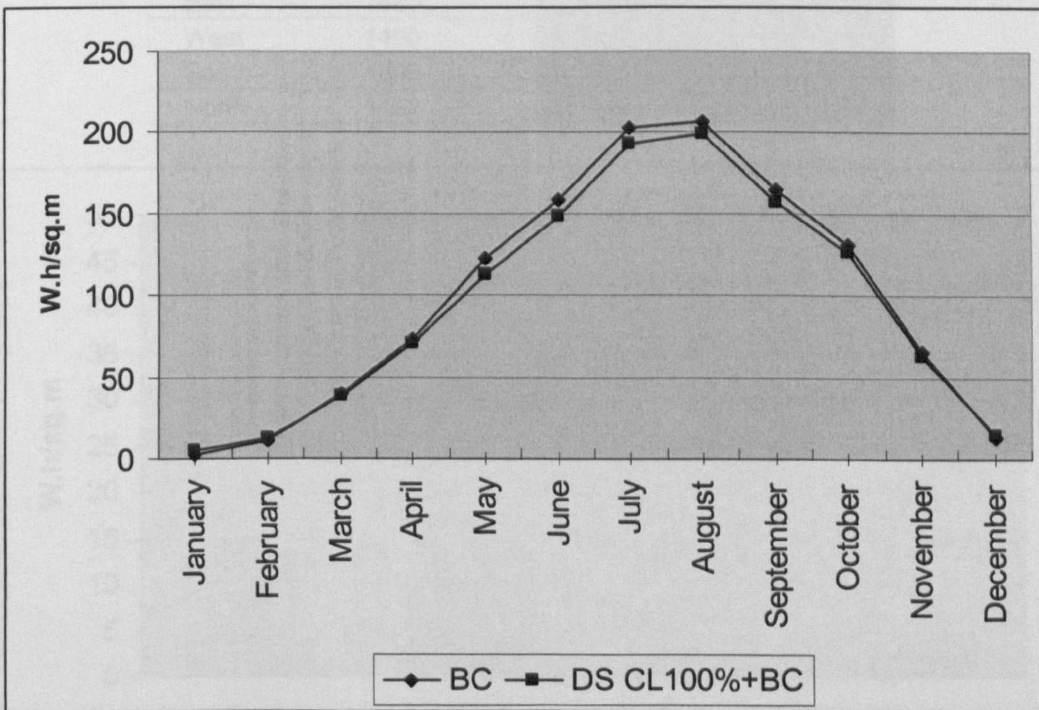

Figure 6: Impact of Transparent Double Skin Facade on North Orientation on total cooling loads

Table 5: Comparison between BC and TDS in Peak Winter

Peak Winter	BC	DS CL100%+BC
East	15	14
West	17	14
South	47	40
	2	5

Table 6: Comparison between BC and TDS in Peak Summer

Peak Summer	BC	DS CL100%+BC
East	238	229
West	239	230
South	216	213
North	207	199

Table 7: Comparison between BC and TDS on annual loads

Annual	BC	DS CL100%+BC
East	1480	1401
West	1490	1413
South	1498	1417
North	1192	1142

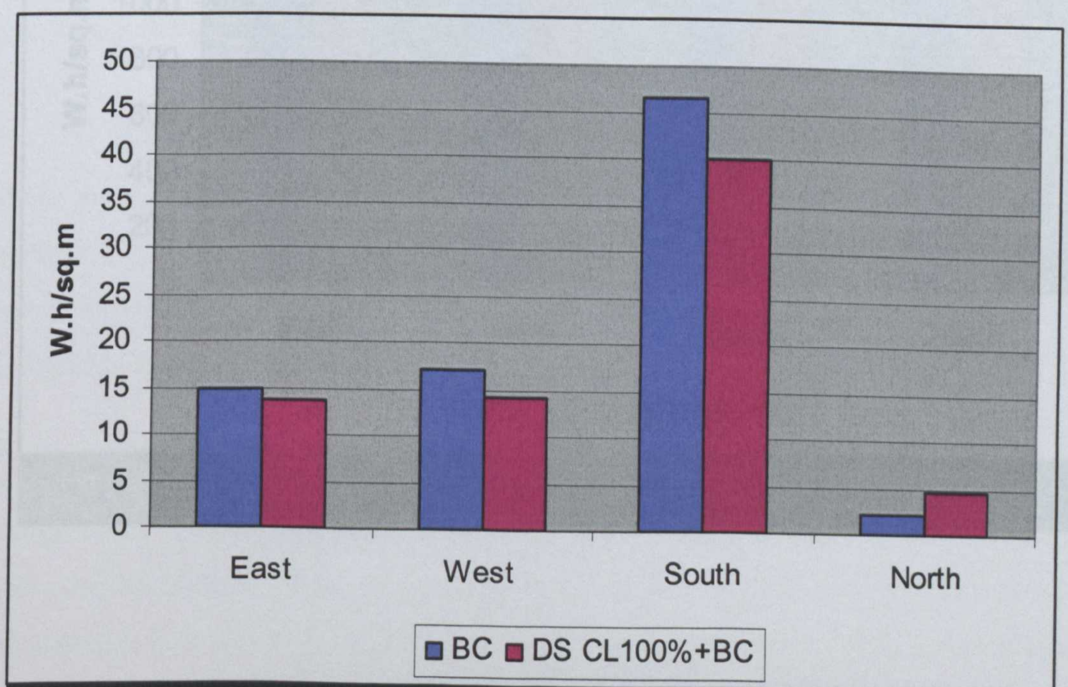

Figure 7: Transparent Double Skin Facade on Peak Winter total Cooling Loads

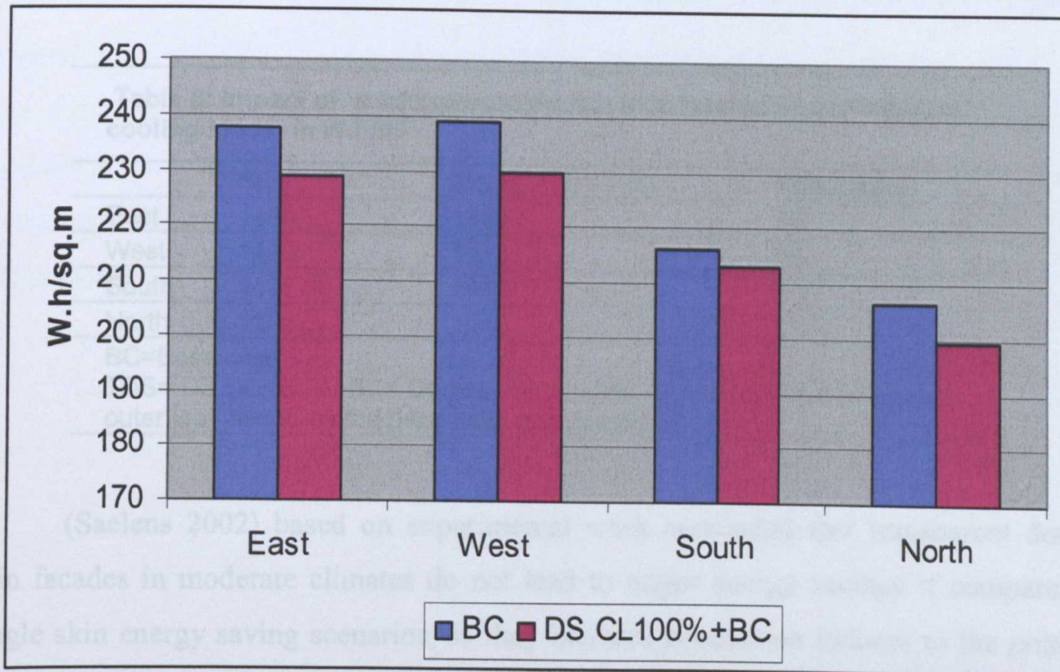

Figure 8: Transparent Double Skin Facade on Peak Summer total cooling loads

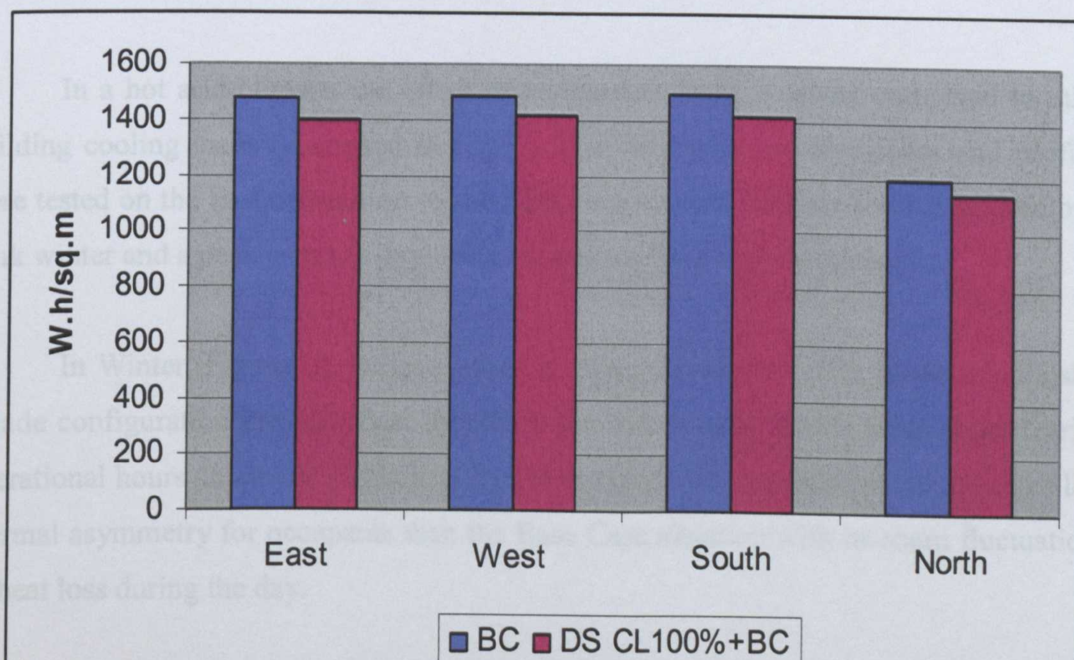

Figure 9: Transparent Double Skin Facade on total annual cooling loads

Table 8: Impact of a transparent double skin facade on annual total cooling loads in W.h/m^2

	BC	DS CL 100%+BC	Reductions
East	1480	1401	5%
West	1490	1413	5%
South	1498	1417	5%
North	1192	1142	4%

BC=Base case
TDS= DS CL 100%+BC= Double Skin façade with 100% clear glazing on outer leaf placed on the base case configuration.

(Saelens 2002) based on experimental work concluded that transparent double skin facades in moderate climates do not lead to major energy savings if compared to single skin energy saving scenarios, as they increase conduction indoors to the point of offsetting the reduction in direct solar penetration indoors in summer. In winter the transparent double skin façade was predicted to increase heat loss through the fabric thus increasing heating loads.

In a hot arid climate, the effect of conduction loads is minor compared to other building cooling loads (discussed in 6.1.1.). The difference in conduction load profiles were tested on the East orientation of the TDS compared to the Base Case is studied on a peak winter and a peak summer day, for a normal working day occupancy.

In Winter, Figure 10, indicates that the presence of the cavity in the double skin façade configuration prevents heat loss from the indoor zone during night time. During operational hours an almost stable heat loss to the cavity is predicted which indicates less thermal asymmetry for occupants than the Base Case situation with its sharp fluctuations of heat loss during the day.

In Summer, during night time, Figure 11, indicates that the Base case façade configuration with its direct contact to the ambient environment losses trapped heat which decreases the start up loads of the mechanical system. The double skin façade on the contrary, indicates that the cavity of the double skin façade configuration prevented heat loss from the East zone during night time which increased the cooling loads on the air conditioning system during start up. During operational hours the conduction loads from the Double Skin façade configuration are generally constant. The almost steady conduction level through the Double Skin is expected to reduce thermal asymmetry for occupants near the façade. Compared to the single skin BC conduction loads during diffuse solar radiation hours were lower in the case of Double Skin facades.

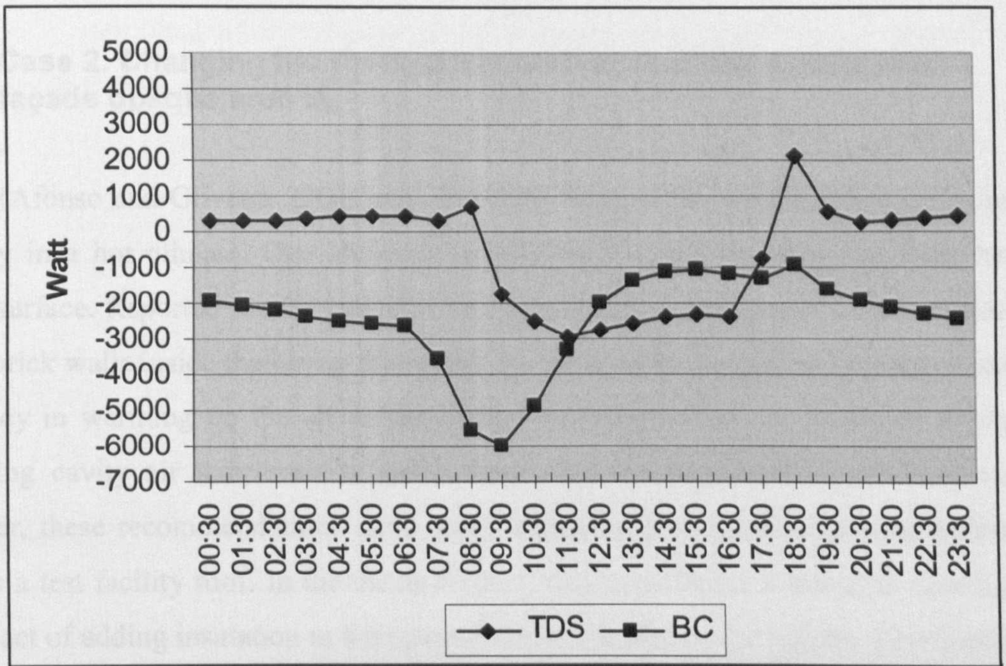

Figure 10: Comparison between TDS and BC conduction loads in peak Winter.

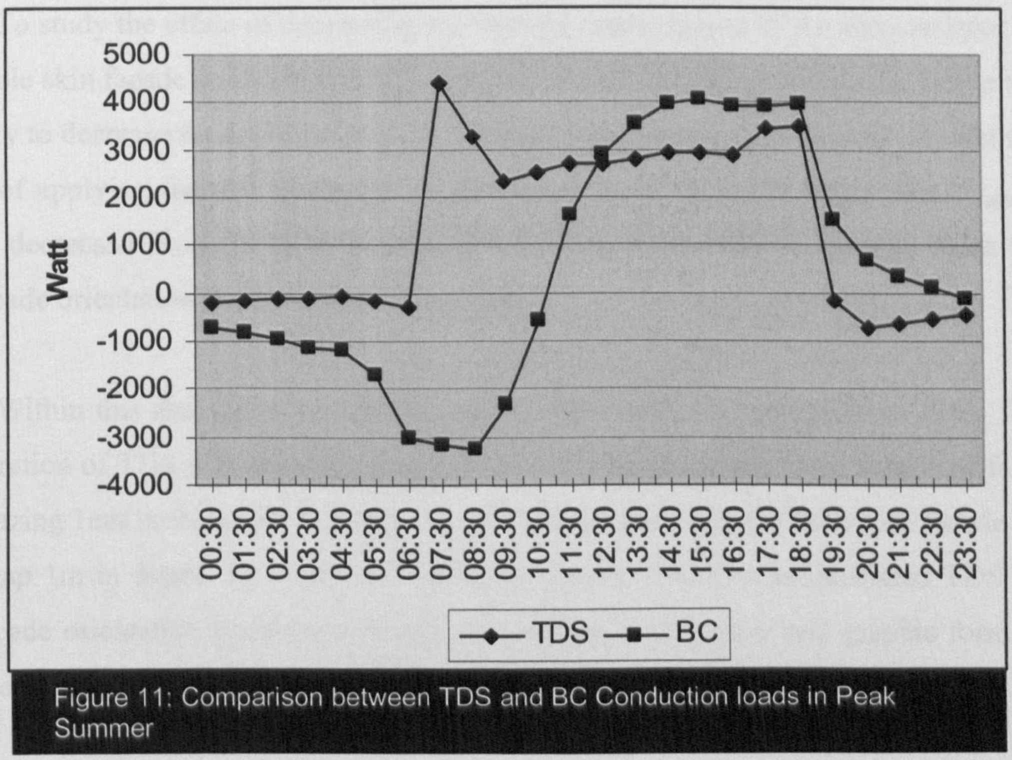

Figure 11: Comparison between TDS and BC Conduction loads in Peak Summer

8.3.1 Case 2: Changing the thermal transmittance of the double skin façade opaque area U_o

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(Afonso and Oliveira 2000) experimentally studied two configurations of a solar chimney in a hot climate. One chimney is fully built of bricks while the other has a glazed surface. Reported results indicated that it is fundamental to use thermal insulation on the brick walls inside the cavity facing the glazed layer to increase the solar assistance efficiency in warming up the air in the cavity instead of warming up the inner walls. Increasing cavity air temperatures had a direct relation to increasing air flow rates. However, these recommendations were based on studying a stand alone solar chimney built on a test facility roof. In the thesis context, this assumption is tested to investigate the impact of adding insulation to the opaque areas of a double skin façade. The impact is predicted on total cooling loads of an occupied office space. Total cooling results are given for a typical m^2 (the fourth level of the model).

To study the effect of decreasing the thermal transmittance of the opaque areas of the double skin façade configuration, the inner façade was insulated on its side facing the air cavity to decrease thermal conductivity between the air cavity and indoors. To test the impact of applying thermal insulation on opaque areas of the inner facade the U_{opaque} value is decreased from 1.7 $W/m^2.K$ to 0.37 $W/m^2.K$ and assessed on monthly bases for each façade orientation on the typical floor level.

Within this analysis a transparent double skin façade is referred to as TDS. The configuration of TDS is externally composed of a full height second skin façade of fully clear glazing 1cm in thickness. The second skin is separated from the base case façade by an air gap 1m in depth. To compare between an insulated and an un-insulated TDS on each façade orientation simulation results are given in both tabular and graphic form to facilitate comparison between cases.

In Winter, comparing an insulated to an un-insulated TDS, between the month of November to March, on the East (Table 9and Figure 12), West (Table 10 and Figure 13), South (Table 11 and Figure 14), and North oriented facades (Table 12 and Figure 15) insulating the opaque part of the inner façade led to a significant increase in Winter total cooling loads on a typical m^2. Adding insulation to the transparent double skin façade configuration (TDS), led to an approximate doubling of peak Winter cooling loads on all façade orientations (Table 13 and Figure 16).

In Summer, comparing an insulated to an un-insulated TDS, between the month of July to August , on the East (Table 9and Figure 12), West (Table 10 and Figure 13), South (Table 11 and Figure 14), and North oriented facades (Table 12 and Figure 15) insulating the opaque part of the inner façade led to an insignificant decrease in Summer total cooling loads on all orientations. Compared to an un-insulated TDS the decrease in peak summer cooling loads on all orientations was predicted to be between 2-5W.h/m^2 which is equivalent to a maximum of 3% reductions of the peak cooling loads (Table 14 and Figure 17).

Due to the contrasting performance of increasing the façade insulation between the Winter and Summer seasons, the annual performance must also be considered. Adding insulation is predicted to increase the total cooling loads on all façade orientations (Table 15 and Figure 18). It is predicted that in comparison to the Base Case adding insulation to the TDS offsets the benefit of the transparent double skin facade in decreasing total cooling loads.

In Winter, Comparing an insulated TDS to the Base Case, adding insulation to the TDS increased all winter loads on all orientations between November and March. This increase in total cooling winter loads is predicted to be between 8-11W.h/m^2 in winter. In January, when cooling loads are predicted to be the minimum, compared to the base case adding insulation to the opaque area of the TDS increased the cooling loads as much as five folds, while in other winter month the increase is in the order of 50% increase. As the base case façade configuration is the worst performance among tested façade variables, this leads to the conclusion that adding an insulated TDS to the Base Case will increase (rather than decrease) total cooling loads than the base case in Winter.

In Summer, comparing an insulated TDS to the Base Case, the insulated TDS reduced total cooling loads in the summer month of July-August. On annual basis the reductions of annual total cooling loads were insignificant (Table 15 and Figure 18).

The previous findings leads to the conclusion that insulating double skin facades when the internal opaque areas are of heavy mass may lead to undesirable increases in annual total cooling loads.. This is attributed to decreased heat loss from the fabric to the external environment. Due to its insignificant impact on decreasing peak loads and its overall impact on increasing the annual cooling loads the insulated-TDS is eliminated from further simulations as an option for refurbishment.

Table 9: Comparison between un-insulated TDS and insulated TDS on the East Orientation

EAST ORIENTATION (total cooling load in W.h/m^2)			
	BC	DS CL100%+BC	DS CL100%+BC+insul
January	15	14	30
February	30	28	42
March	66	63	69
April	105	98	102
May	148	138	135
June	184	173	168
July	230	219	213
August	238	229	226
September	196	186	184
October	158	150	150
November	83	79	92
December	28	26	43
	1480	1401	1454

Table 10: Comparison between un-insulated and insulated TDS on the West Orientation

WEST ORIENTATION (total cooling load in W.h/ m^2)			
	BC	DS CL100%+BC	DS CL100%+BC+insul
January	17	14	33
February	31	29	43
March	68	64	70
April	106	100	104
May	150	142	138
June	185	176	169
July	232	219	214
August	239	230	228
September	194	185	183
October	159	152	152
November	82	76	92
December	28	26	44
	1490	1413	1470

Table 11: Comparison between insulated and un-insulated TDS on the South Orientation

SOUTH ORIENTATION (total cooling load in W.h/ m^2)

	BC	DS CL100%+BC	DS CL100%+BC+insul
January	47	40	68
February	52	46	66
March	72	68	67
April	87	84	86
May	120	116	112
June	153	144	138
July	201	193	191
August	216	213	211
September	194	186	183
October	179	168	161
November	115	104	121
December	61	55	72
Total	1498	1417	1476

Table 12: Comparison between un-insulated and insulated TDS on the North Orientation

NORTH ORIENTATION (total cooling load in W.h/ m^2)

	BC	DS CL100%+BC	DS CL100%+BC+insul
January	2	5	10
February	11	13	20
March	39	38	43
April	73	71	73
May	123	113	116
June	159	149	150
July	203	193	189
August	207	199	198
September	165	157	157
October	132	126	127
November	65	63	75
December	14	15	25
	1192	1142	1184

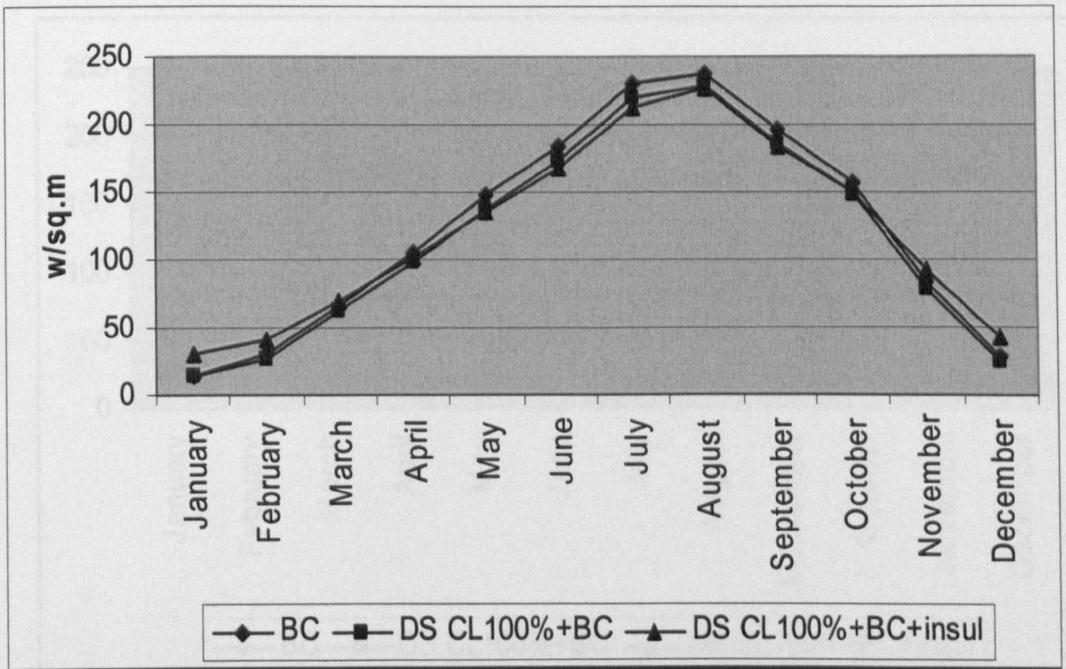


Figure 12: Impact of reducing Uo on TDS on the East Orientation

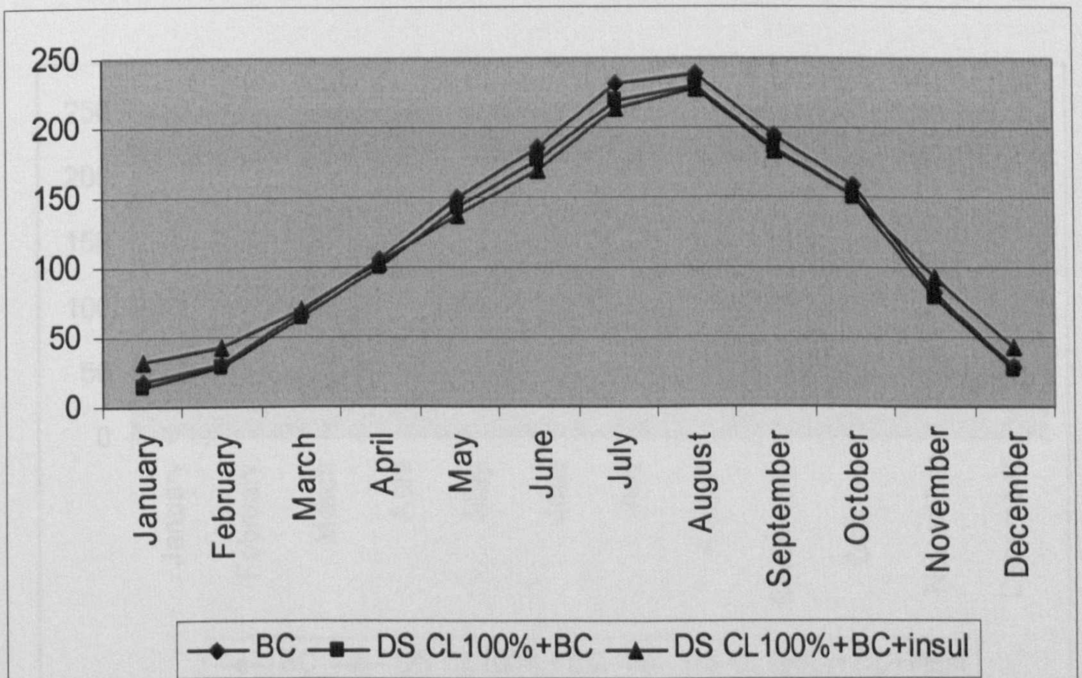


Figure 13: Impact of reducing Uo on TDS on the West Orientation

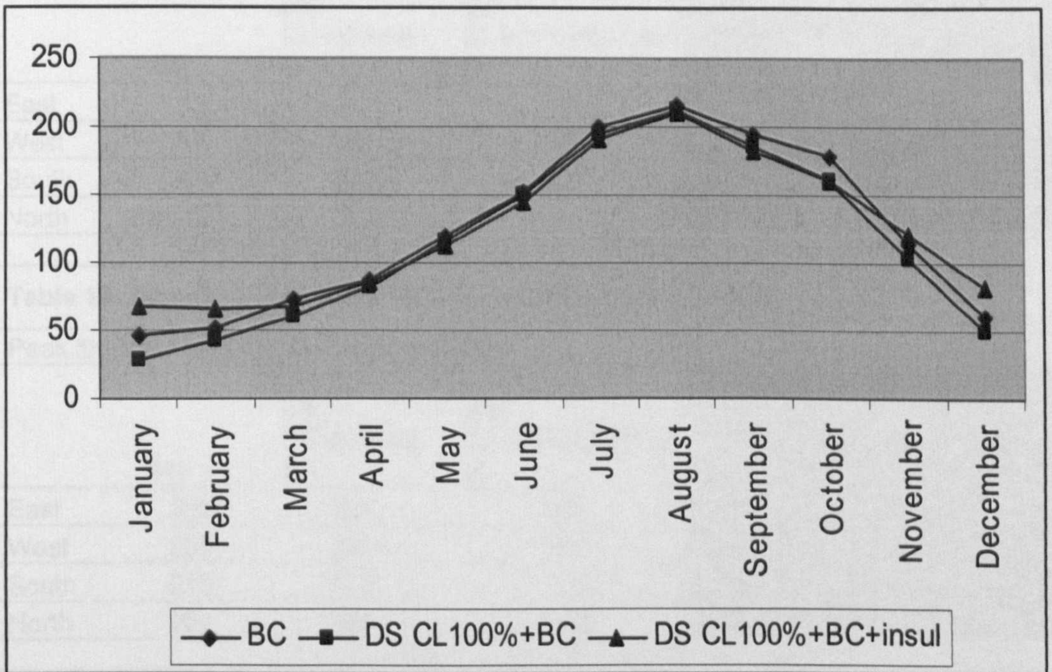


Figure 14: Impact of reducing U_o of TDS on the South Orientation

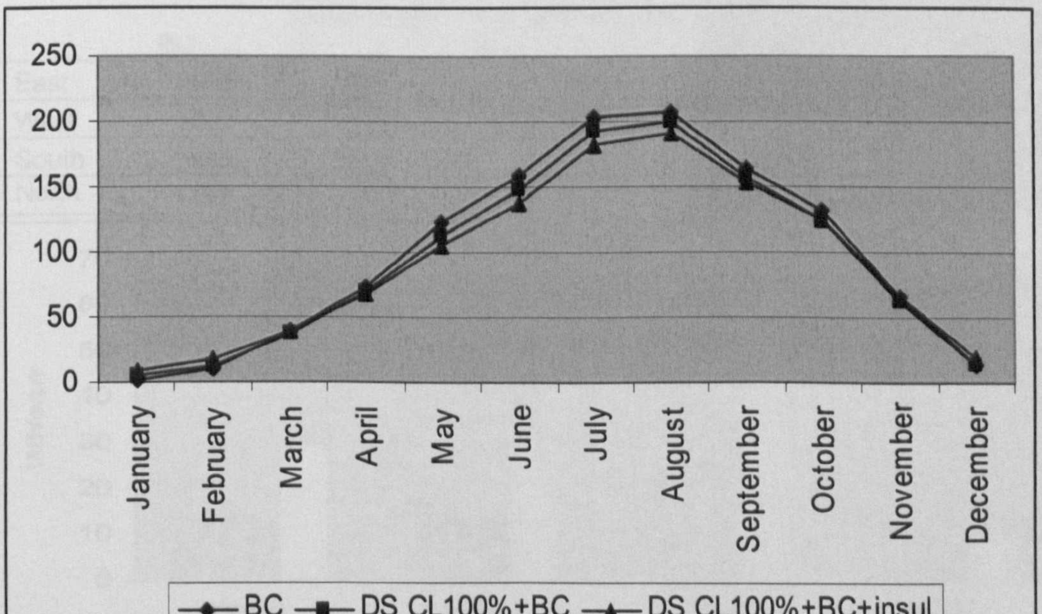


Figure 15: Impact of reducing U_o of TDS on the North orientation

Table 13: Impact of insulated TDS on peak Winter total cooling loads

Peak Winter total cooling loads in W.h/m^2

	BC	DS CL100%+BC	DS CL100%+BC+insul	Increase than BC	Increase than DS CL 100%+BC
East	15	14	30	50%	54%
West	17	14	33	48%	57%
South	47	40	68	31%	41%
North	2	5	10	79%	55%

Table 14: Impact of insulating TDS on peak Summer total cooling loads

Peak Summer total cooling loads in W.h/m^2

	BC	DS CL100%+BC	DS CL100%+BC+insul	Reductions from BC	Decrease than DS CL 100%+BC
East	238	229	226	5%	1%
West	239	230	228	5%	1%
South	216	213	211	2%	1%
North	207	199	198	4%	1%

Table 15: Impact of insulating TDS on the annual total cooling load

Annual total cooling loads in W.h/m^2

	BC	DS CL100%+BC	DS CL100%+BC+insul	Reductions from BC	Increase than DS CL 100%+BC
East	1480	1401	1454	2%	4%
West	1490	1413	1470	1%	4%
South	1498	1417	1476	1%	4%
North	1192	1142	1184	1%	4%

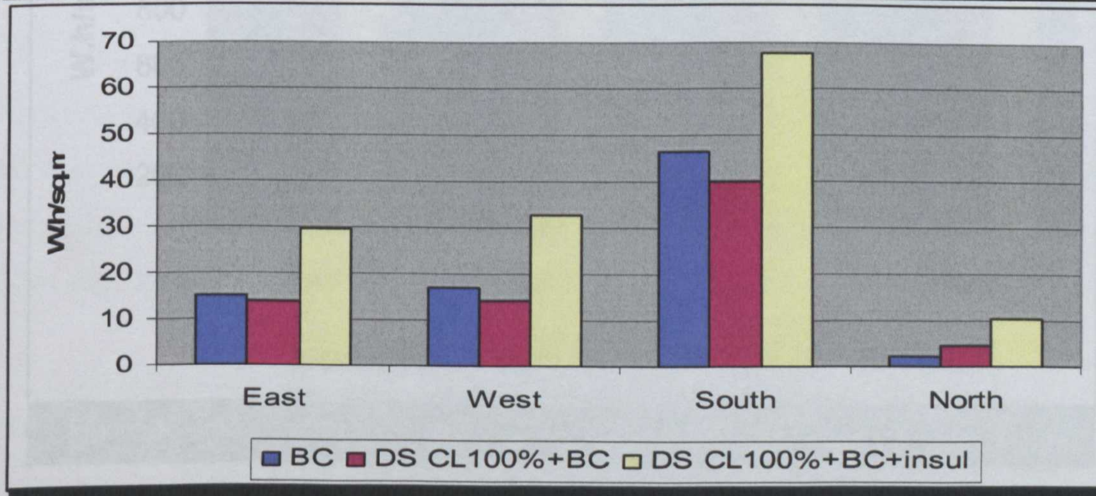


Figure 16: Impact of insulating TDS on Peak Winter total cooling loads

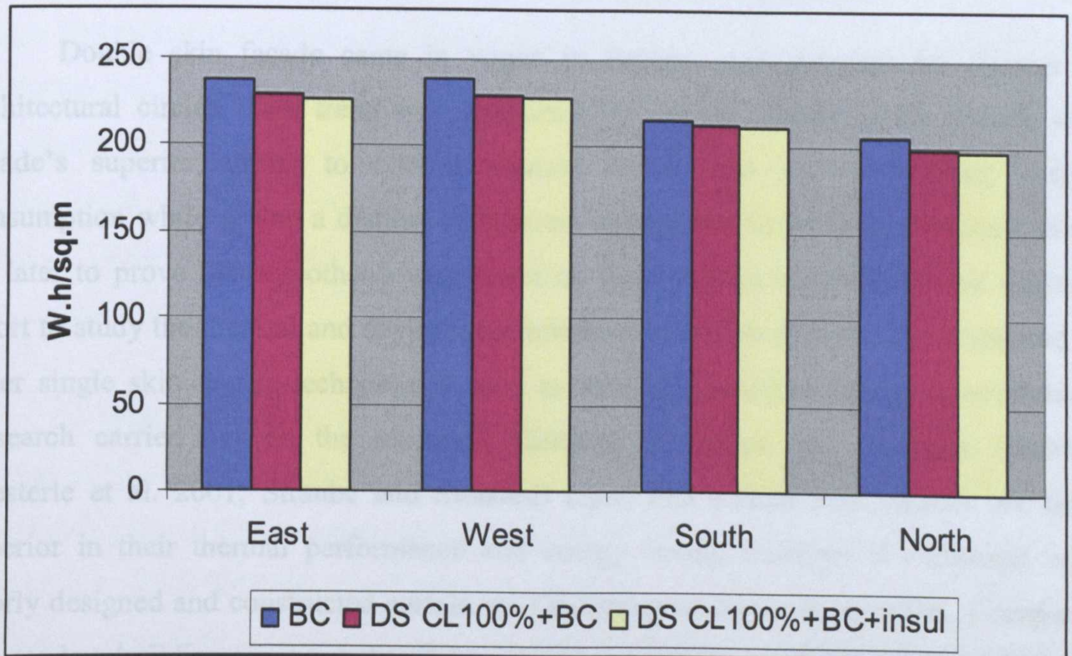


Figure 17: Impact of insulating TDS on peak Summer total cooling loads

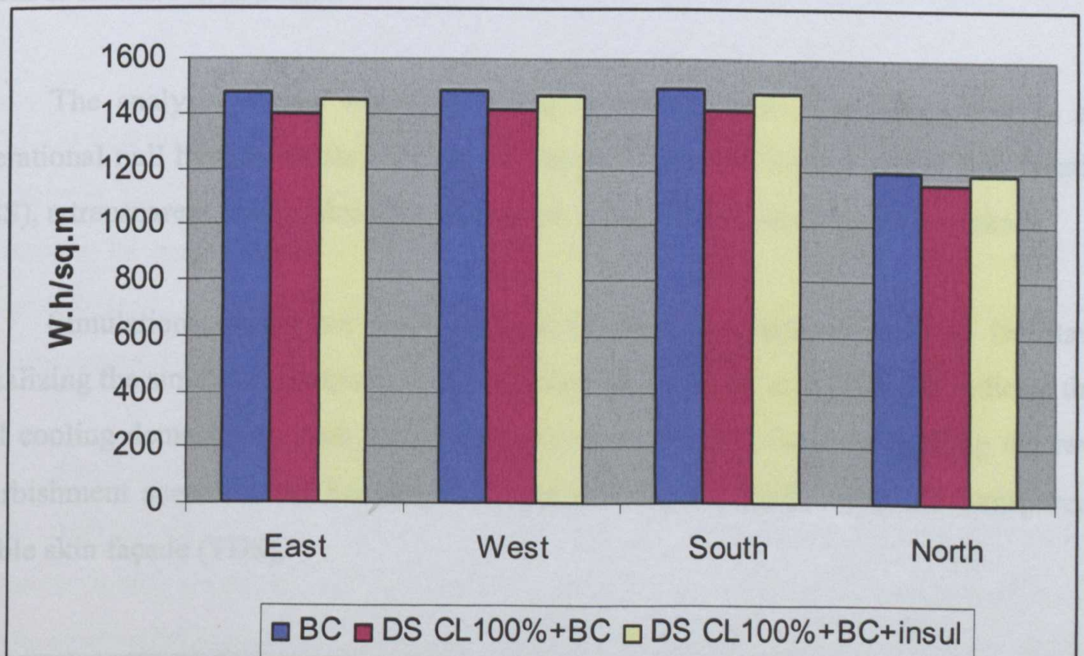


Figure 18: Impact of Insulating TDS on annual total cooling loads

8.4 A Transparent Double skin or a Benchmark Single Skin?

Double skin façade came in vogue in Europe, and attracted the interest of architectural circles. This trend was supported by various claims of the double skin façade's superior ability to control climate, noise, and reduce building energy consumption while giving a distinct transparent appearance to building. Studies carried on later to prove this hypothesis cast doubt on these claims which led to an ongoing effort to study the thermal and daylight performance of double skin facades compared to other single skin façade technologies used to minimize building energy consumption. Research carried out on the moderate climates of Europe and Northern America (Oesterle et al. 2001; Straube and Straaten) argue that double skin facades are only superior in their thermal performance and energy saving potential if compared with poorly designed and constructed curtain wall buildings of the early seventies. Compared to a modern building constructed to tighter building envelope regulations, using advanced building glazing and wall construction materials, double skin facades do not indicate any significant energy savings leaving building owners with the added costs of constructing a second façade without any real economic return. However, no concrete resolution to any claims is founded in literature.

The analysis is then extended to test hypothesis four. Hypothesis four is an Operational null hypothesis stating that: 'Compared to an benchmark single skin façade (BSS), a transparent double skin façade may not achieve lower cooling load demands'

Simulations results are given in both tabular and graphical form to facilitate visualizing the simulation outputs. Table 16,Table 17,Table 18, and Table 19, indicate the total cooling demands on each façade orientation on monthly basis, comparing the two refurbishment scenarios the benchmark single skin façade (BSS)* with the transparent double skin façade (TDS).

* BSS is based on findings from the previous simulations of a single skin façade in chapter Six. The façade configuration is based on 40% WWR in single reflective glazing, while the opaque area is of an un-insulated single brick layer plastered from both sides

On Monthly basis , comparing the total cooling load of the benchmark single skin façade (BSS) and the transparent double skin façade (TDS) on a typical m^2 Simulation results for East(Table 16 and Figure 19), West (Table 17 and Figure 20), South (Table 18 and Figure 21), indicated that using TDS as a refurbishment solution increases total cooling loads on these facades year round compared to the BSS. The North oriented facades (Table 19 and Figure 22) had a different response that is discussed separately later in this section.

In Winter, although the TDS decreased the total cooling demand between the months of November to April than the Base Case on the East, West and South facades, the TDS is predicted to increase total cooling loads than the BSS in winter. Peak Winter total cooling loads indicates this increase to almost a 1.5 to double the total cooling loads on these orientations compared to the BSS peak winter total cooling loads. This maybe attributed to increasing conduction gains to the interior during the morning hours and preventing heat loss from the fabric to the ambient environment by night. Therefore, the performance of the BSS on these three orientations is predicted to be superior in its ability to reduce cooling loads than TDS.

In Summer, analyzing the data cross-sectionally, Table 21 and Figure , indicate that during the peak summer month on East, West and South facades using BSS is superior in its capability to reduce total cooling load demands, this maybe attributed to the BSS superior ability in reflecting the incident solar radiation penetration indoors than the transparent double skin façade (TDS).

The North façade indicated a different thermal response. (Figure 22), indicates minor differences on monthly total cooling loads between the two refurbishment scenarios, which indicates it is less sensitive to both façade refurbishment scenarios. In Winter (Figure 24) there is an increase in total cooling loads when a transparent double skin façade, compared to a minor heating load when reflective glazing is introduced on the base case. In the peak summer month (Figure 23), indicates that there is negligible difference between using OSS or a transparent double skin façade on the total cooling loads. Therefore, it maybe argued that to increase the penetration of daylight a transparent double skin façade maybe preferable on this façade bearing in mind a minor energy penalty in winter.

Analyzing the difference between the two refurbishment scenarios on annual basis (Table 22 and Figure 25) there is an increase in total cooling loads demand when TDS is used, on annual basis this is predicted to be 4% higher than using a bench mark single skin refurbishment scenario. It is predicted that on annual basis the use of TDS increased the annual total cooling loads by an average of 100W.h/sq.m. This increase is considered considerable if multiplied by an actual office building area. This confirms the thesis hypothesis and concurs with (Oesterle et al. 2001; Saelens 2002) findings that using a transparent double skin façade is not the optimum façade configuration in terms of energy savings.

However, the difference between the two façade refurbishment scenarios might not rule out suggesting using a transparent single skin for façade refurbishment. If the original façade of the building is of historic value, there is a concern that using reflective glazing may alter the historic aesthetics of the façade's architecture. A transparent double skin may incur an annual energy penalty, but in this case might be seen as a sustainable façade refurbishment option in terms of its ability to reduce air pollution and weathering factors on the façade, and thus reducing the frequency of façade refurbishment. From an internal point of view a transparent double skin facade reduces noise levels penetrating indoor spaces especially in high traffic urban areas.

Another aspect for consideration is that in winter times, the temperature in the cavity of the transparent double skin is higher than the winter ambient temperatures, with careful building system management natural ventilation maybe introduced indoors even to higher floors. This is a dimension outside the scope of this thesis but is worthwhile of consideration in future research and may lead to reductions in cooling loads in winter.

Table 16: Comparison between BSS and a transparent double skin on the East facades

EAST ORIENTATION (total cooling load in W.h/m²)			
	BC	S.Refl	DS CL100%+BC
January	15	6	14
February	30	18	28
March	66	50	63
April	105	87	98
May	148	129	138
June	184	165	173
July	230	212	219
August	238	220	229
September	196	179	186
October	158	143	150
November	83	72	79
December	28	19	26
	1480	1299	1401

Table 17: Comparison between BSS and a transparent double skin on the West facade

WEST ORIENTATION (total cooling load in W.h/m²)			
	BC	S.Refl	DS CL100%+BC
January	17	8	14
February	31	19	29
March	68	51	64
April	106	87	100
May	150	130	142
June	185	172	176
July	232	213	219
August	239	220	230
September	194	177	185
October	159	143	152
November	82	72	76
December	28	19	26
	1490	1311	1413

Table 18: Comparison between BSS and a transparent double skin on the South facade

SOUTH ORIENTATION (total cooling load in W.h/m^2)			
	BC	S.Refl	DS CL100%+BC
January	47	25	40
February	52	32	46
March	72	55	68
April	87	77	84
May	120	112	116
June	153	145	144
July	201	193	193
August	216	206	213
September	194	177	186
October	179	156	168
November	115	92	104
December	61	39	50
	1498	1311	1417

Table 19: Comparison between BSS and a Transparent Double Skin on the North Facade

NORTH ORIENTATION (total cooling load in W.h/m^2)			
	BC	S.Refl	DS CL100%+BC
January	2	-1	5
February	11	8	13
March	39	34	38
April	73	67	71
May	123	112	113
June	159	149	149
July	203	195	193
August	207	200	199
September	165	159	157
October	132	127	126
November	65	62	63
December	14	11	15
	1192	1121	1142

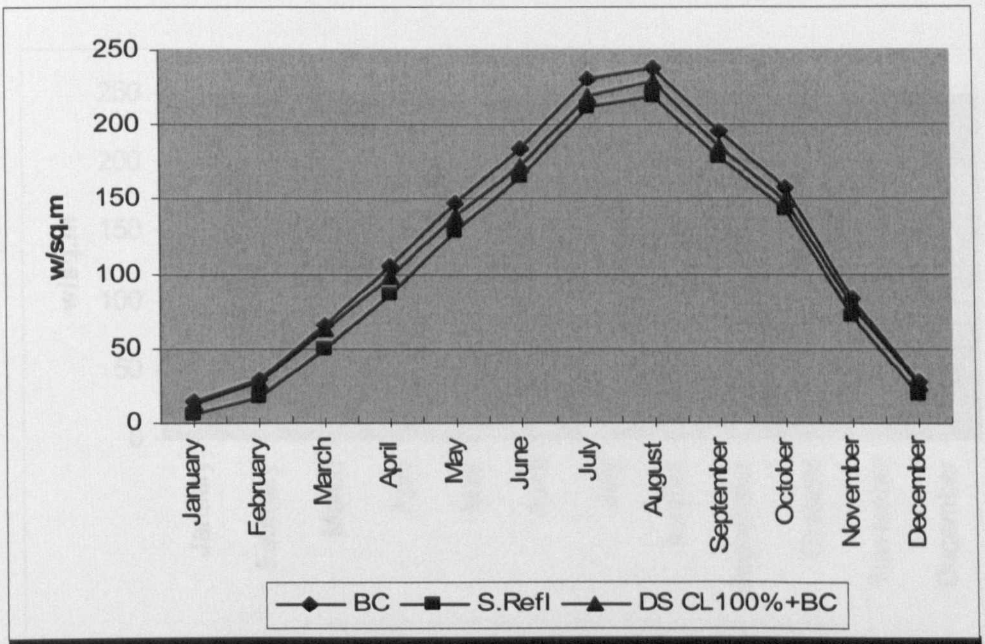


Figure 19: Comparison between BSS and TDS on the East façade on total cooling loads

BC: Base Case, **BSS=S. Ref:** benchmark single skin, **TDS= DS Cl 100% +BC** Transparent double skin façade placed on the base case.

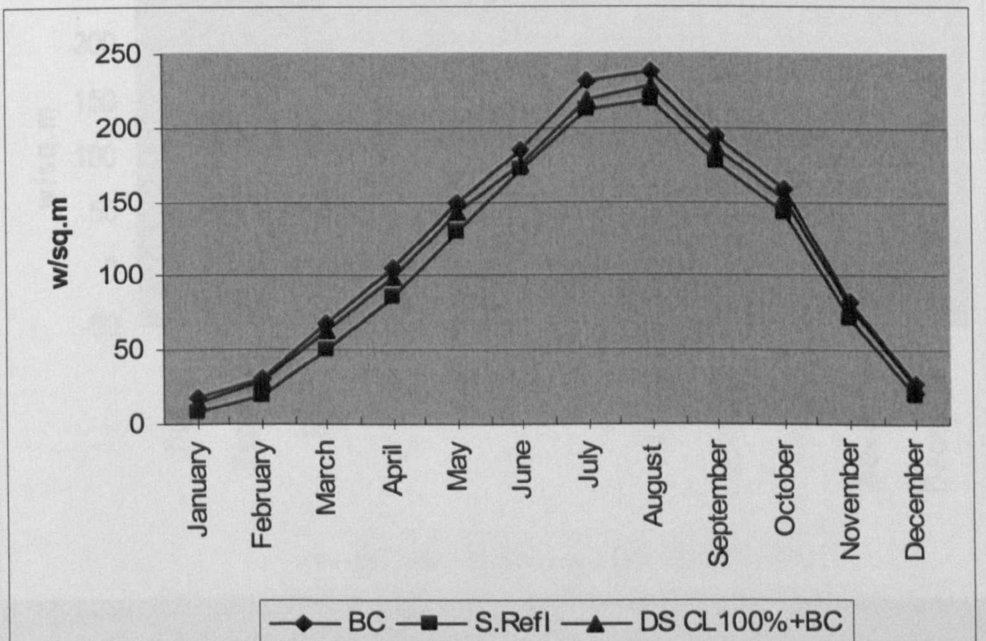


Figure 20: Comparison between BSS and TDS on the West Façade on total cooling loads

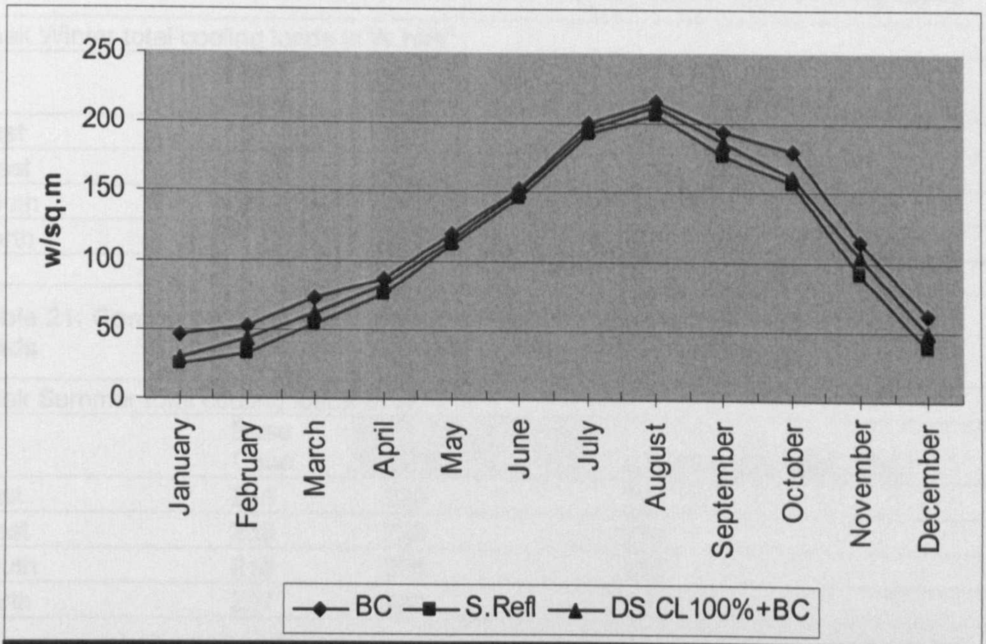


Figure 21: Comparison between BSS and TDS on the South orientation on total cooling loads

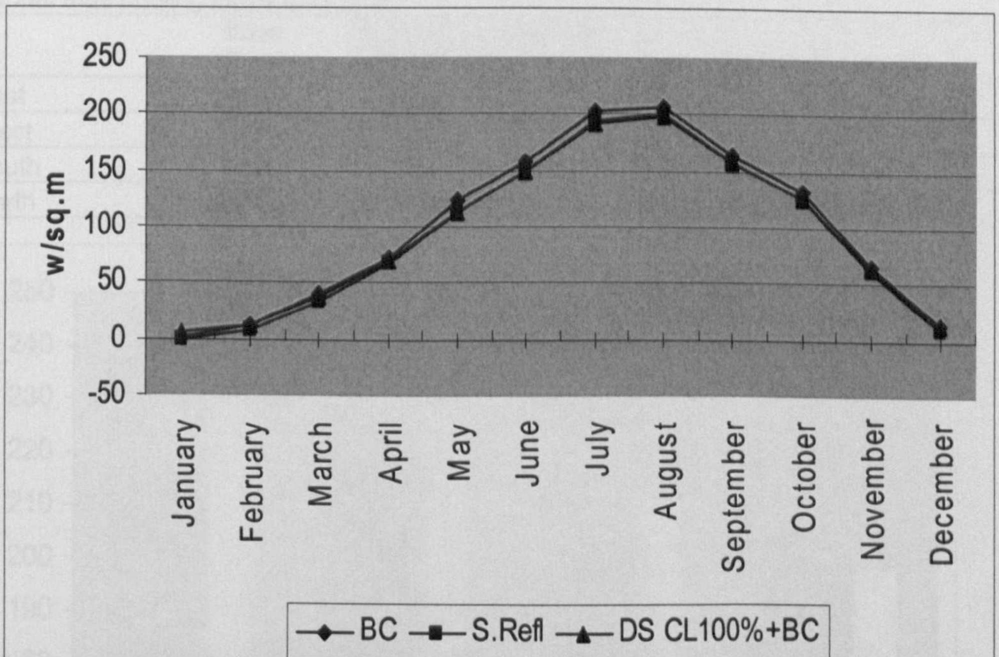


Figure 22: Comparison between BSS and TDS on the North orientation on total cooling loads

Table 20: Comparison between BSS and TDS in peak Winter total cooling loads

Peak Winter total cooling loads in W.h/m^2

	Base Case	BSS	Clear Double Skin (TDS)
East	15	6	14
West	17	8	14
South	47	25	40
North	2	-1	5

Table 21: Comparison between BSS and TDS in peak Summer total cooling loads

Peak Summer total cooling loads in W.h/ m^2

	Base Case	BSS	Clear Double Skin (TDS)
East	238	220	229
West	239	220	230
South	216	206	213
North	207	200	199

Table 22: Comparison between BSS and TDS on annual total cooling loads

Annual total cooling loads in W.h/ m^2

	Base Case	BSS	Clear Double Skin (TDS)
East	1480	1299	1401
West	1490	1311	1413
South	1498	1311	1417
North	1192	1121	1142

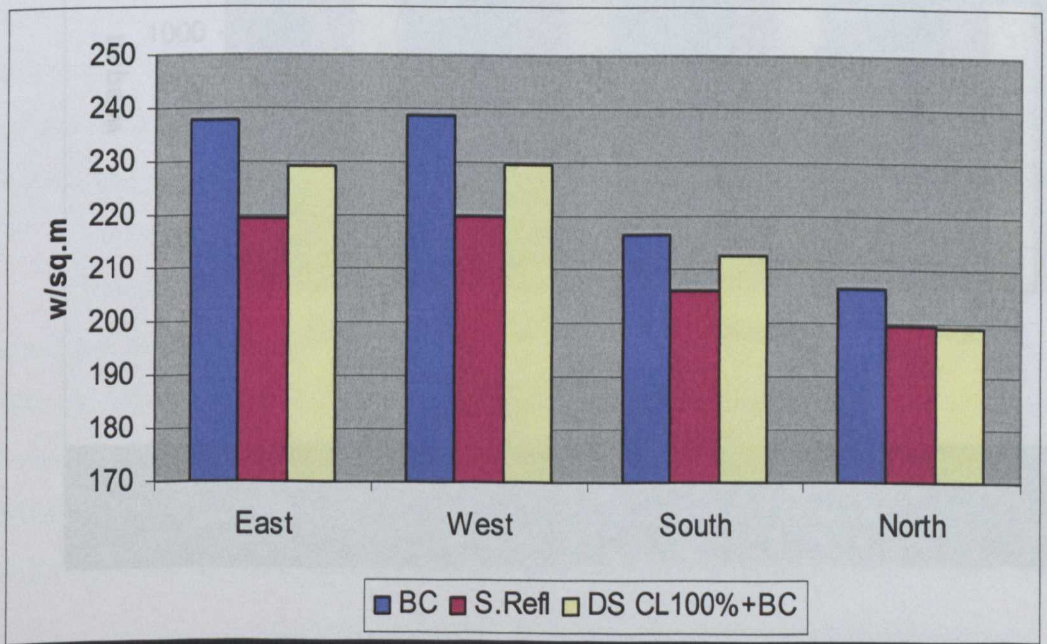


Figure 23: Comparison between BSS and transparent double skin on peak summer total cooling loads

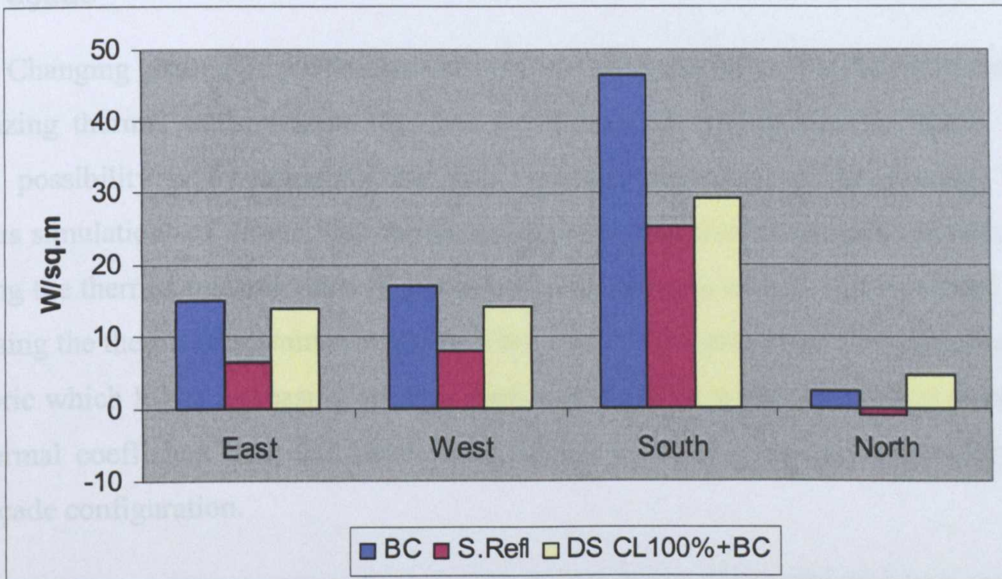


Figure 24: Comparison between BSS and transparent double skin on peak winter total cooling loads

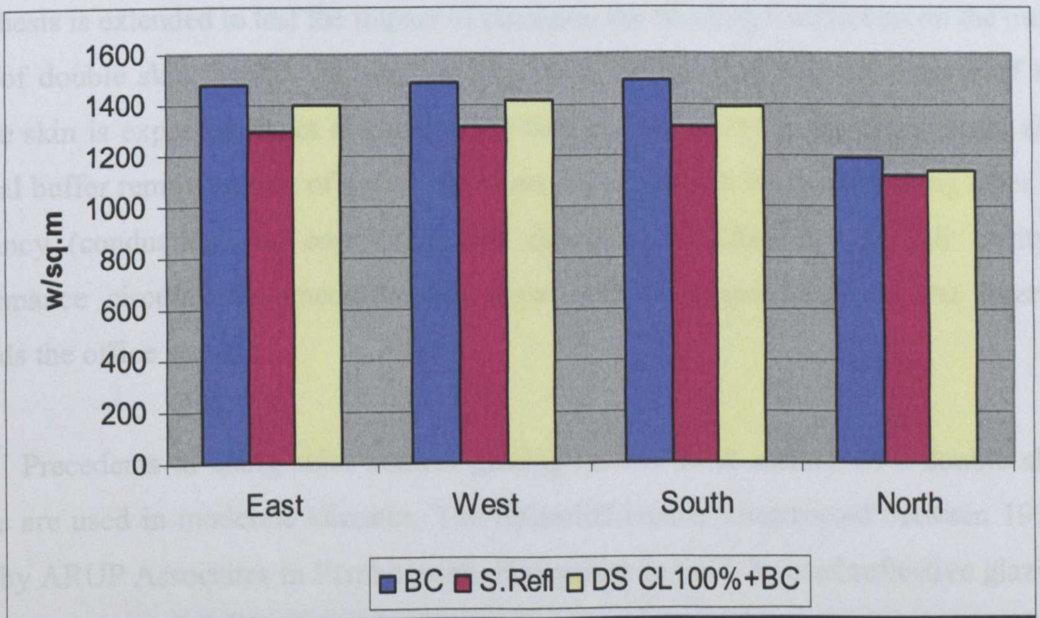


Figure 25: Comparison between BSS and a transparent double skin facade on annual total cooling loads

8.5 Changing the Glazing Properties of the Outer Layer of the Double Skin Façade

Changing glazing properties involves two possible scenarios. The first is to reduce the glazing thermal transmittance Ug, this is achieved by adding glazing layers. The second possibility is by changing the solar shading properties of the glazing. The previous simulations of Single Skin façade configurations indicated the adverse effect of reducing the thermal transmittance of glazing (Ug) on the base case. It was predicted that decreasing the thermal transmittance within a hot arid climate prevented heat loss through the fabric which led to increasing cooling loads especially in winter. Therefore reducing the thermal coefficient was eliminated from further simulation analysis on the double skin façade configuration.

From an energy saving perspective, the previous section (8.4) indicated the superiority of using the benchmark single skin façade than a transparent double skin in achieving less cooling load demands. Changing the Shading Coefficient of glazing was predicted to reduce total cooling loads on the single skin façade scenarios. Therefore, this hypothesis is extended to test the impact of changing the Shading Coefficient on the outer layer of double skin facades on total cooling loads. In this case, the outer layer of the double skin is expected to act as direct solar barrier. The cavity is expected to act as a thermal buffer removing part of the energy transmitted through the outer glazing layer by buoyancy (conduction and convection and direct solar radiation). The air cavity's performance circumvents uncomfortable glass surface temperatures on the interior towards the office space

Precedents to using solar control glazing on the outer surface of a double skin façade are used in moderate climates. The Briarcliff House, constructed between 1978-1983 by ARUP Associates in Farnborough, Hampshire in the UK, used reflective glazing to control direct solar radiation on the South Façade of the building. Performance of the reflective double skin façade is assessed as successful in providing solar and acoustical buffering, while reducing radiant temperatures on inside glass surfaces (Bachman 2003).

Changing the Shading coefficient of the exterior glazing of the double skin façade configuration is examined by: adding solar control glazing to the outer surface of the double skin façade configuration. The properties of glazing used in this investigation are presented in Chapter Six, Table 6.

8.5.1 Case 3: Using Body Tinted Glazing on the Exterior Surface of the Double Skin Façade Configuration.

The use of body tinted glazing is advocated for in double skin facades in moderate climates especially to control heat gain on the Southern oriented facades in winter months. In Norman Foster's building of Willis Faber Dumas insurance Headquarters in London a tinted double skin façade is used on the South orientation and is claimed to improve the visual light transmittance indoors while maintaining the thermal performance of the air gap (Bachman 2003).

The use of body tinted glazing is single skin façade refurbishment scenarios indicated minor reduction of the total cooling loads on all façade orientations. However, it is worth examining in the case of a double skin façade configuration as the cavity plays a major role in extracting the glazing surface elevated temperatures to the exterior environment.

Simulations results on monthly basis compares using body tinted glazing as the external layer of the double skin façade configuration to the base case configuration and to a transparent double skin configuration (TDS).

On monthly basis, compared to the TDS using body tinted glazing on the external layer of the double skin façade configuration indicated reductions in total cooling loads year round on the East (Table 23 and Figure 26), West (Table 24 and Figure 27), South (Table 25 and Figure), and North orientations (Table 25 and Figure 29). This indicates that year round the performance of the tinted double skin façade supersedes the performance of the transparent single skin façade in reducing total cooling load demands on all façade orientations.

However, the performance of the tinted double skin façade becomes more effective in reducing total cooling loads between the month of May till September on all facades. This is attributed to the ability of the external layer to control and intercept the direct solar radiation entering indoors.

In Peak Winter months, Table 27and Figure 30, in comparison to the TDS, the peak loads on all façade orientations indicated that using a body tinted glazing as the external layer of the double skin façade reduced the peak Winter cooling loads on the East, West and South orientations. The analysis indicates that using a tinted double skin facade is more effective on the south orientation in winter than the East and West facades as it reduced the direct solar radiation indoors. The predicted reductions on this façade in peak winter are significant, reducing 14W.h/sq.m equating to 35% reductions in the total cooling loads.

Compared to the Base case the peak winter total cooling loads were reduced significantly on the East (40 %), West (39%), and South orientations (45%). However the North façade indicated a minor increase of 2 W.h/m^2, this may be attributed to the shading Coefficient of the tinted glazing used, which still allows for a high penetration of direct solar radiations indoors, which decreases the effect of the solar control glazing in controlling direct radiation. The performance of the cavity contributes to this increase as it increases the effect of conduction loads in the mornings and prevents its loss during the night by the layer of surrounding warm air.

Night time ventilation may be introduced and automatically controlled to flush the building of excessive heat gains by night, however this aspect is outside the scope of the thesis and remains to be investigated in future research.

In Peak Summer Table 28 and Figure 31, compared to TDS using the body tinted double skin façade significantly reduced cooling loads on all façade orientations, reducing total cooling loads on East and West façade 15% and on the South and North by approximately 19% .

In peak summer, Table 28 and Figure 31, Compared to the Base case, using the body tinted double skin façade significantly reduced cooling loads on all façade orientations, reducing total cooling loads on East and West façade 18% and on the South and North by approximately 20%.

On annual basis, comparing the tinted double skin façade to the transparent double skin façade, Table 29 and Figure 32, the tinted double skin façade provided monthly total cooling load reductions which when added up to an annual sum indicated the superiority of tinted glazing in reducing the annual total cooling loads than the base case. According to façade orientation, on the East, West and South around 18% reduction while on the North a 20% reduction is predicted. The 2% difference between the North orientation and the three other orientations is considered insignificant.

This leads to the conclusion that using a body tinted double skin façade as a refurbishment scenario is better in decreasing peak winter and summer, as well as annual cooling loads than a transparent double skin façade on all orientations.

Table 23: Using tinted glazing on DS on the East Orientation

East Orientation (Total cooling load in W.h/m^2)			
	Base Case	Clear Double Skin (TDS)	Tinted Double Skin
January	15	14	9
February	30	28	19
March	66	63	47
April	105	98	75
May	148	138	111
June	184	173	142
July	230	219	187
August	238	229	196
September	196	186	158
October	158	150	127
November	83	79	65
December	28	26	19
Total	1480	1401	1155

Table 24: Using Tinted Glazing on DS on the West Orientation

West Orientation (Total cooling load in W.h/ m^2)			
	Base Case	Clear Double Skin (TDS)	Tinted Double Skin
January	17	14	10
February	31	29	20
March	68	64	47
April	106	100	76
May	150	142	113
June	185	176	143
July	232	219	188
August	239	230	196
September	194	185	157
October	159	152	127
November	82	76	65
December	28	26	19
Total	1490	1413	1161

Table 25: Using tinted glazing on DS on the South orientation

South Orientation (Total cooling load in W.h/ m^2)			
	Base Case	Clear Double Skin (TDS)	Tinted Double Skin
January	47	40	26
February	52	46	31
March	72	68	52
April	87	84	65
May	120	116	95
June	153	144	122
July	201	193	168
August	216	213	176
September	194	186	156
October	179	168	142
November	115	104	87
December	61	55	44
Total	1498	1417	1164

Table 26: Using tinted glazing on DS on the North orientation

North Orientation (Total cooling load in W.h/ m^2)			
	Base Case	Clear Double Skin (TDS)	Tinted Double Skin
January	2	5	4
February	11	13	10
March	39	38	30
April	73	71	56
May	123	113	85
June	159	149	127
July	203	193	157
August	207	199	162
September	165	157	125
October	132	126	101
November	65	63	55
December	14	15	10
Total	1192	1142	916

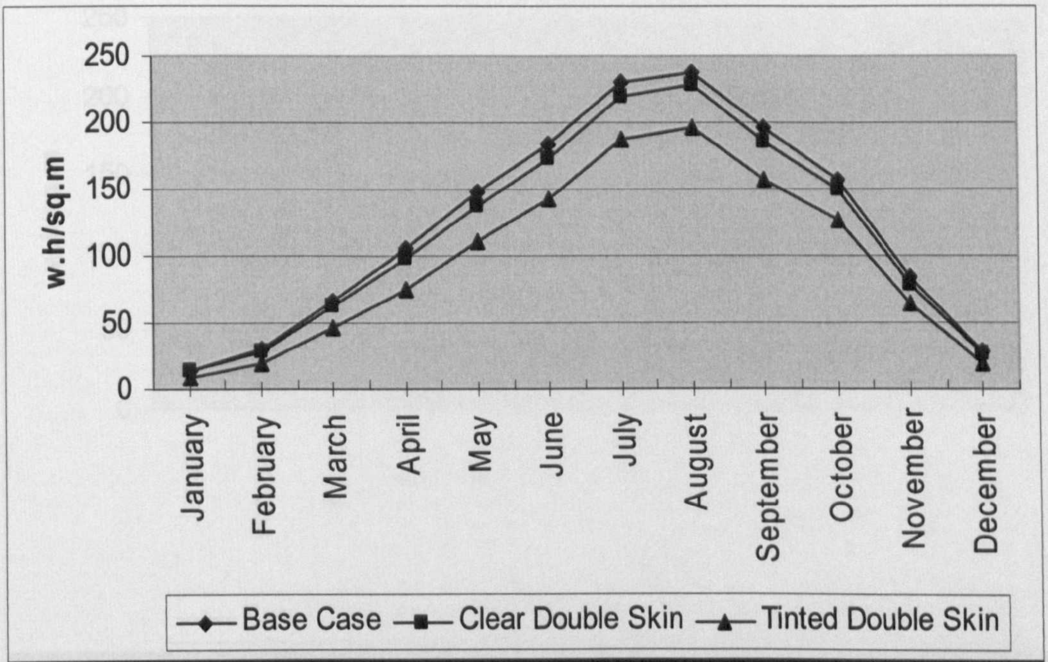


Figure 26: Using tinted glazing on DS on the East Orientation

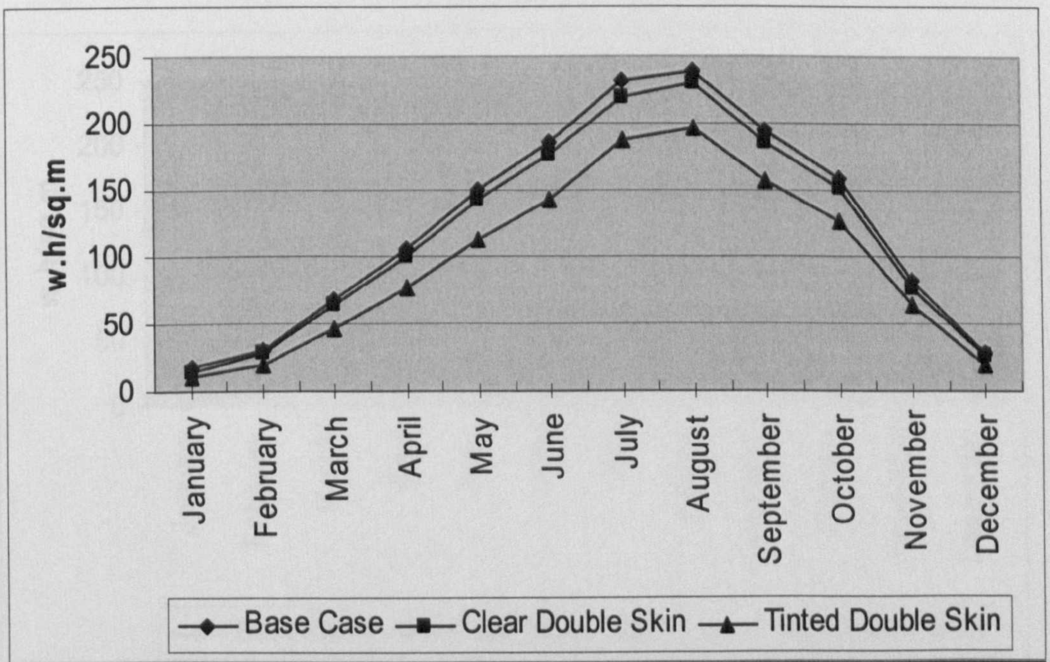


Figure 27: Using tinted glazing on DS on the West Orientation

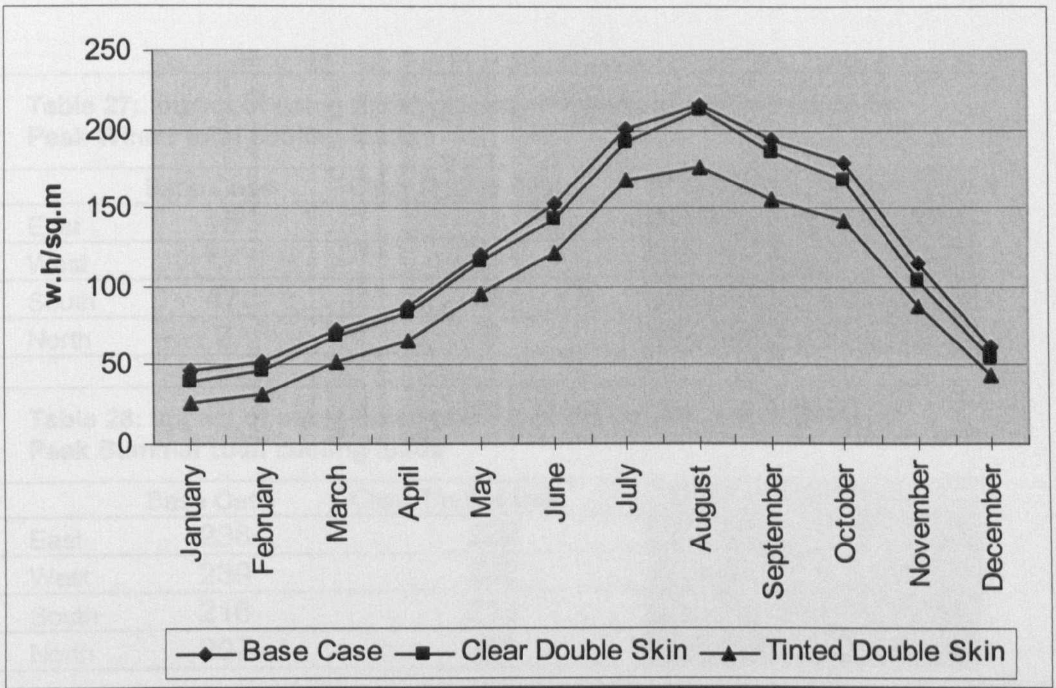


Figure 28: Using tinted glazing on DS on the South Orientation

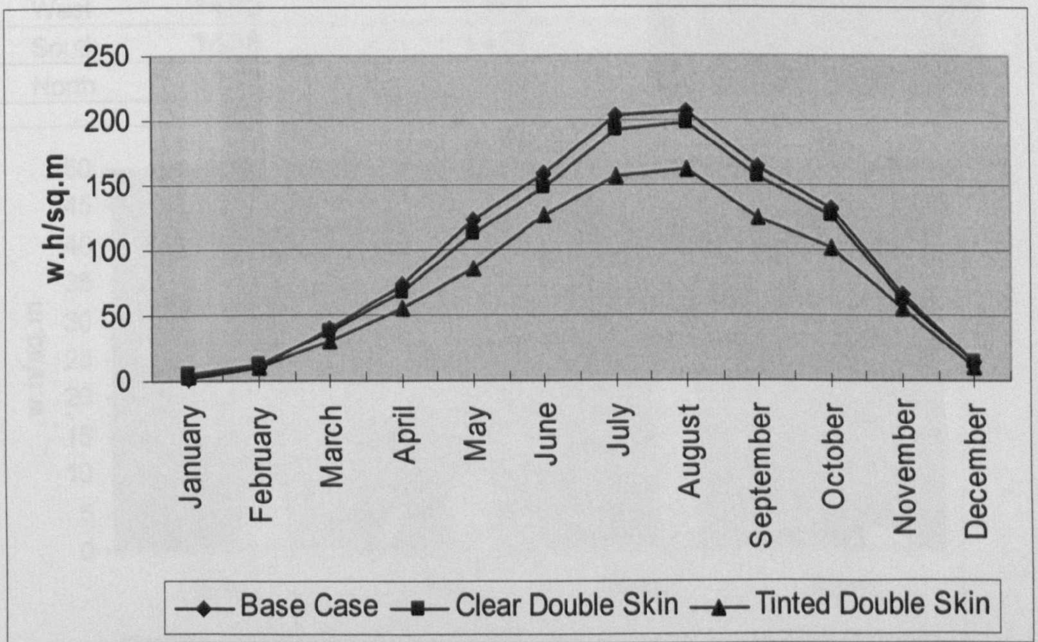


Figure 29: Using tinted glazing on DS on the North orientation

Table 27: Impact of using tinted glazing of the Double Skin Facade on Peak Winter total cooling loads

	Base Case	Clear Double Skin	Tinted Double Skin
East	15	14	9
West	17	14	10
South	47	40	26
North	2	5	3

Table 28: Impact of using tinted glazing of the Double Skin Facade on Peak Summer total cooling loads

	Base Case	Clear Double Skin	Tinted Double Skin
East	238	229	196
West	239	230	196
South	216	213	176
North	207	199	162

Table 29: Impact of using tinted glazing of the Double Skin Facade on annual total cooling loads

	Base Case	Clear Double Skin	Tinted Double Skin
East	1480	1401	1155
West	1490	1413	1161
South	1498	1417	1164
North	1192	1139	921

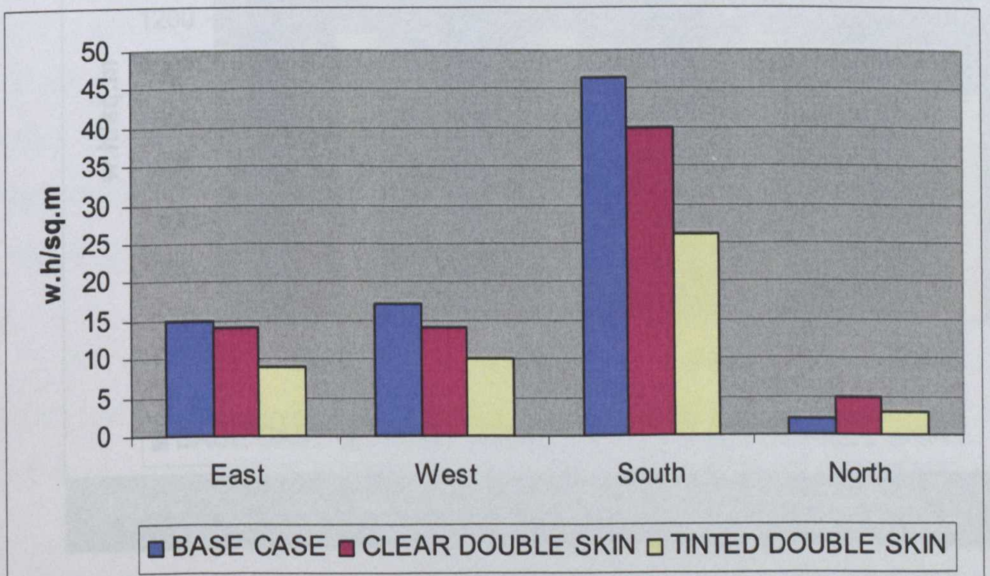


Figure 30: Impact of using tinted glazing of the Double Skin Facade on Peak Winter total cooling loads

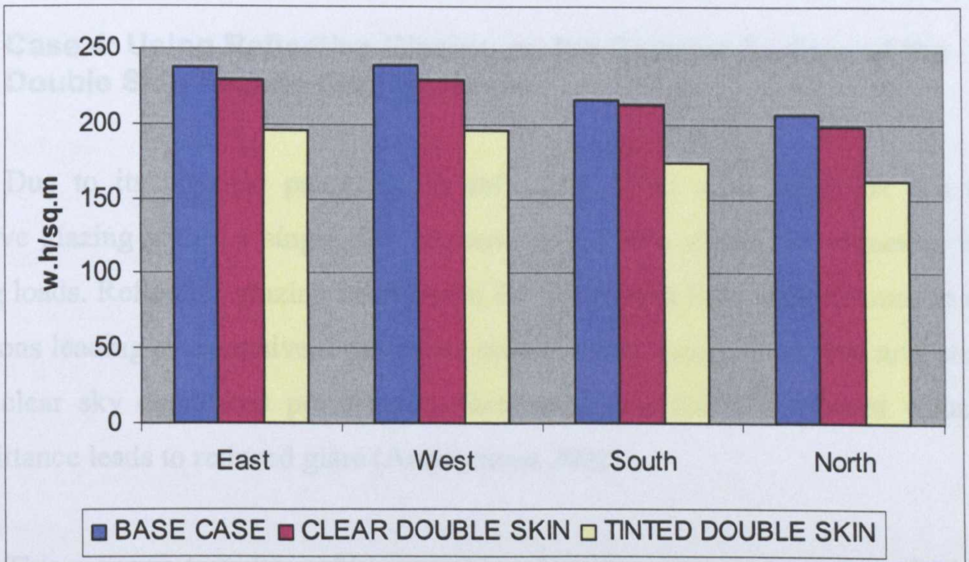


Figure 31: Impact using tinted glazing in the Double Skin Facade on peak total Summer cooling loads

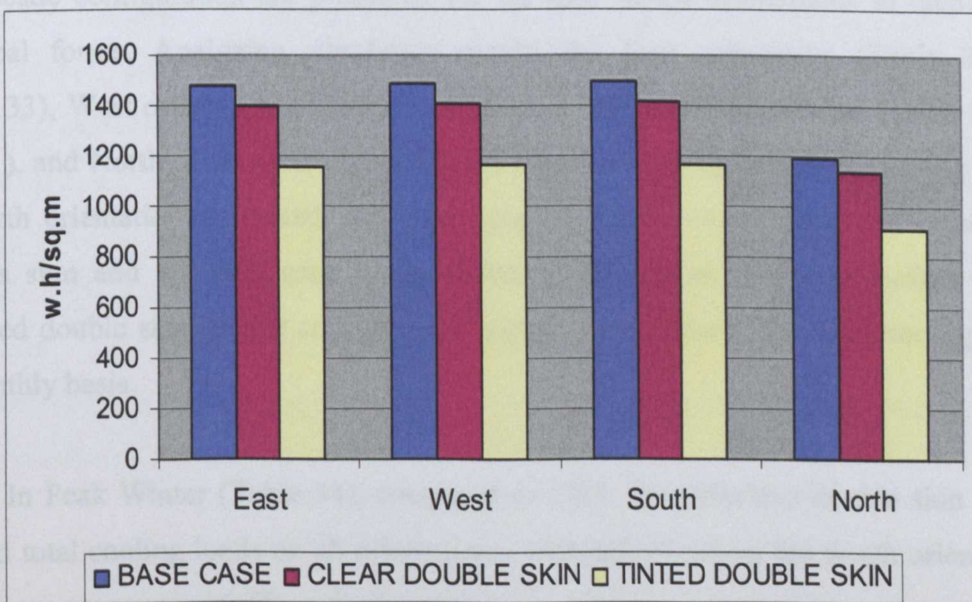


Figure 32: Impact of using tinted glazing on annual total cooling loads

8.5.2 Case 4: Using Reflective Glazing on the Exterior Surface of the Double Skin Façade Configuration.

Due to its physical properties in reflecting direct solar radiation, the use of reflective glazing within a single skin scenario indicated a significant reduction in total cooling loads. Reflective glazing is criticized for its reduced light transmittance in cloudy conditions leading to excessive dependence on electricity usage, but in hot arid countries where clear sky conditions prevail manufacturers claim that the reduced visual light transmittance leads to reduced glare (Anonymous 2002).

This scenario tests its performance if used on the outer surface of the double skin façade. Simulation results are compared to the Base Case and transparent double skin (TDS) scenarios.

On monthly basis, simulation results for using reflective glazing on the double skin façade configuration are presented for the four façade orientations in tabular and graphical forms. Analyzing simulation results the East orientation (Table 30 and Figure 33), West orientation (Table 31 and Figure 34), South orientation (Table 32 and Figure), and North orientation (Table 33 and Figure 36: Using reflective glazing on DS on North orientation) indicated that when simultaneously compared to the transparent doubles skin and the base case, using reflective glazing on the outer surface of the proposed double skin façade configuration significantly reduced the total cooling loads on monthly basis.

In Peak Winter (Table 34), compared to TDS, the reflective double skin façade reduced total cooling loads on all orientations, with reductions on the South orientations being more pronounced (60% reductions).

Compared to the Base Case the reflective double skin façade considerably decreased the peak winter total cooling loads expect between 25% to 30% according to façade orientation. The North façade which indicated insensitivity to this façade refurbishment option, but indicated that the reflective double skin façade did not increase the winter peak cooling loads as the previous scenario testing the tinted double skin façade.

In Peak Summer (Table 35), compared to TDS, the reductions of the total cooling loads was considerable. On all façade orientations, the average of total cooling load reductions is 30%. Compared to the Base case, using a reflective double skin façade decreased annual total cooling loads even further than those compared to the TDS. On the East and west orientations reductions are up to 34% and 31% on the South and North orientation.

On annual basis (Table 36), the reflective double skin superseded the performance of the transparent double skin façade (TDS), this is related to the ability of the reflective surfaces decrease total cooling loads year round on all orientations. On all façade orientations, the average of annual total cooling load reductions is 35%. Compared to the Base case the reductions are predicted to be on an average of 40% for all orientations.

In conclusion, it is evident that the performance of a reflective double skin façade is superior to the performance of a transparent double skin façade and leads to considerable reductions of total cooling loads in peak summer, winter and annual total cooling loads. Thus a more energy efficient façade refurbishment option when compared to the performance of the base case.

Compared to the average reductions achieved by the transparent double skin, the tinted double skin façade and the reflective double skin due to their glazing physical properties were found to be superior in their ability to intercept direct solar radiation on all facades. Due to their predicted better performance as a double skin façade configuration, the tinted and reflective double skin facades are referred to collectively as selective double skin facades.

Table 30: Using reflective glazing on DS on the East Orientation

EAST ORIENTATION (Total cooling load in W.h/m^2)

	Base Case	Clear Double Skin	Reflective Double Skin
January	15	14	5
February	30	28	11
March	66	63	31
April	105	98	51
May	148	138	81
June	184	173	106
July	230	219	150
August	238	229	159
September	196	186	126
October	158	150	101
November	83	79	51
December	28	26	13
Total	1480	1401	885

Table 31: Using reflective glazing on DS on the West orientation

WEST ORIENTATION (Total cooling load in W.h/ m^2)

	Base Case	Clear Double Skin	Reflective Double Skin
January	17	14	6
February	31	29	11
March	68	64	31
April	106	100	51
May	150	142	81
June	185	176	107
July	232	219	151
August	239	230	159
September	194	185	124
October	159	152	101
November	82	76	51
December	28	26	13
Total	1490	1413	886

Table 32: Using reflective glazing on DS on the South orientation

SOUTH ORIENTATION (Total cooling load in W.h/ m^2)			
	Base Case	Clear Double Skin	Reflective Double Skin
January	47	40	15
February	52	46	18
March	72	68	33
April	87	84	48
May	120	116	70
June	153	144	98
July	201	193	135
August	216	213	150
September	194	186	124
October	179	168	110
November	115	104	62
December	61	55	23
Total	1498	1417	886

Table 33: Using reflective glazing on DS on the North orientation

NORTH ORIENTATION (Total cooling load in W.h/ m^2)			
	Base Case	Clear Double Skin	Reflective Double Skin
January	2	5	2
February	11	13	4
March	39	38	21
April	73	71	39
May	123	113	69
June	159	149	100
July	203	193	137
August	207	199	144
September	165	157	112
October	132	126	89
November	65	63	43
December	14	15	7
Total	1192	1142	767

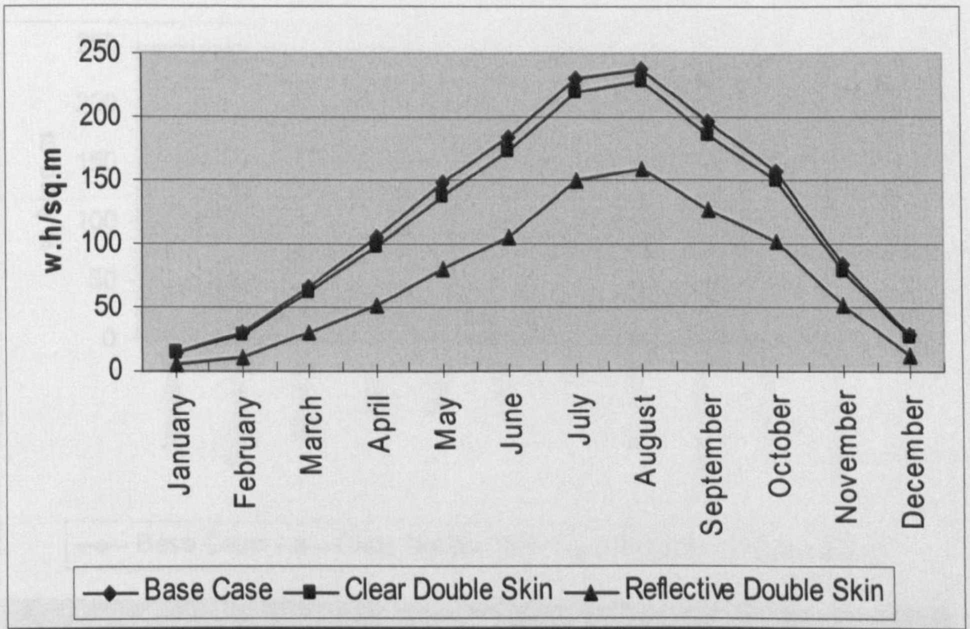


Figure 33: Using reflective glazing on DS on East Orientation

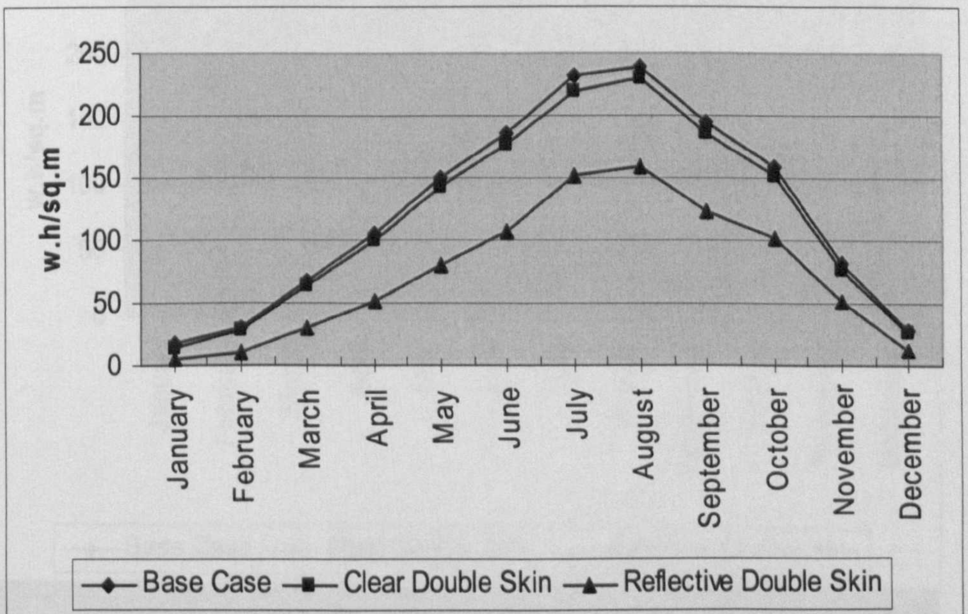


Figure 34: Using reflective glazing on DS on West orientation

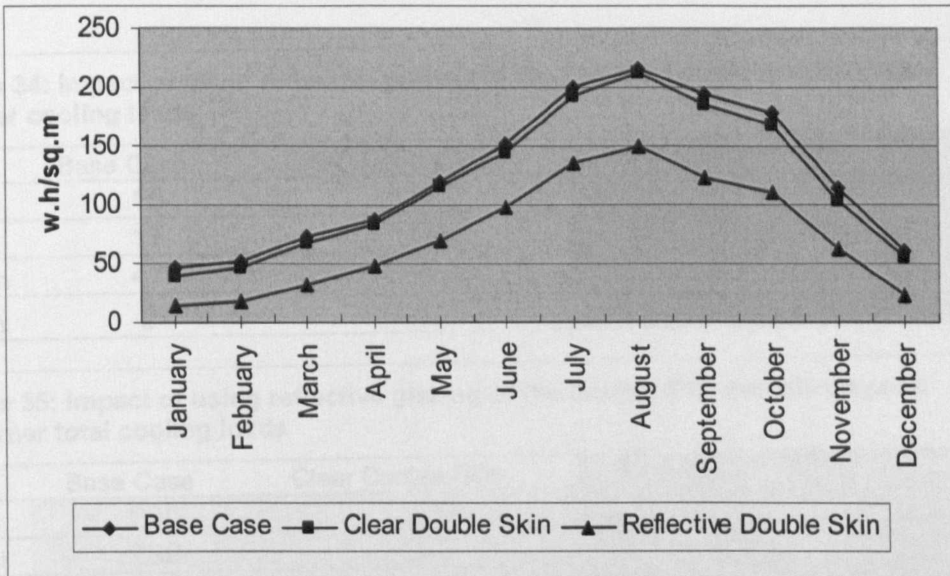


Figure 35: Using reflective glazing on DS on South orientation

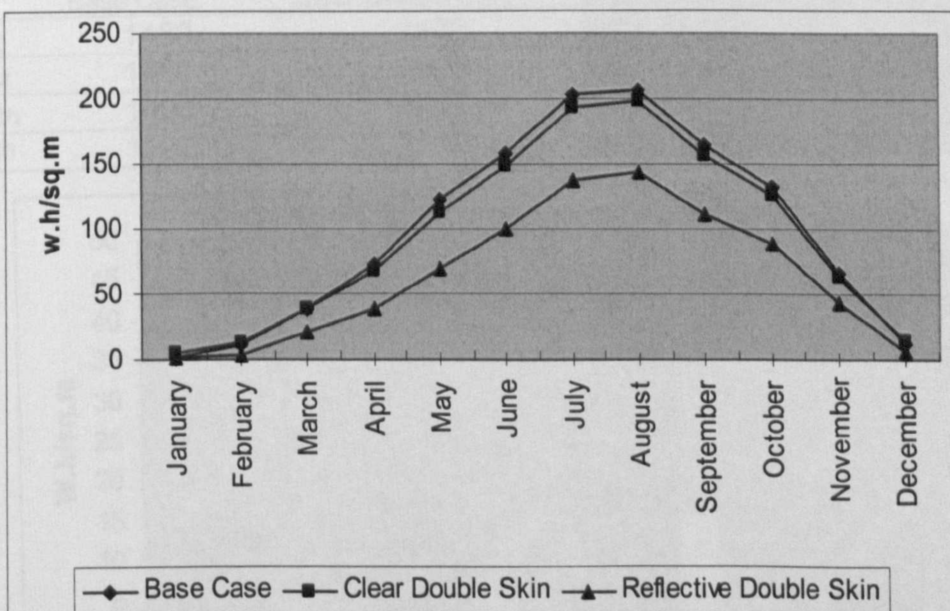


Figure 36: Using reflective glazing on DS on North orientation

Table 34: Impact of using reflective glazing of the Double Skin Facade on peak Winter cooling loads

	Base Case	Clear Double Skin	Reflective Double Skin
East	15	14	5
West	17	14	6
South	47	40	15
North	2	5	2

Table 35: Impact of using reflective glazing of the Double Skin Facade on peak summer total cooling loads

	Base Case	Clear Double Skin	Reflective Double Skin
East	238	229	159
West	239	230	159
South	216	213	150
North	207	199	144

Table 36: Impact of using reflective glazing of the Double Skin Facade on annual total cooling loads

	Base Case	Clear Double Skin	Reflective Double Skin
East	1480	1401	885
West	1490	1413	886
South	1498	1417	886
North	1192	1142	767

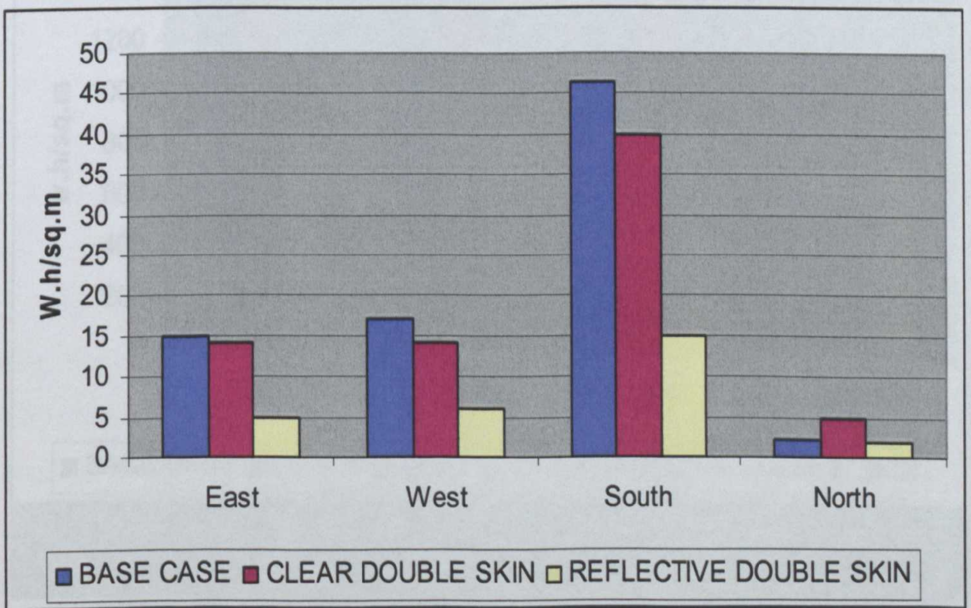


Figure 37: Impact of using reflective glazing of the Double Skin Facade on peak Winter total cooling loads

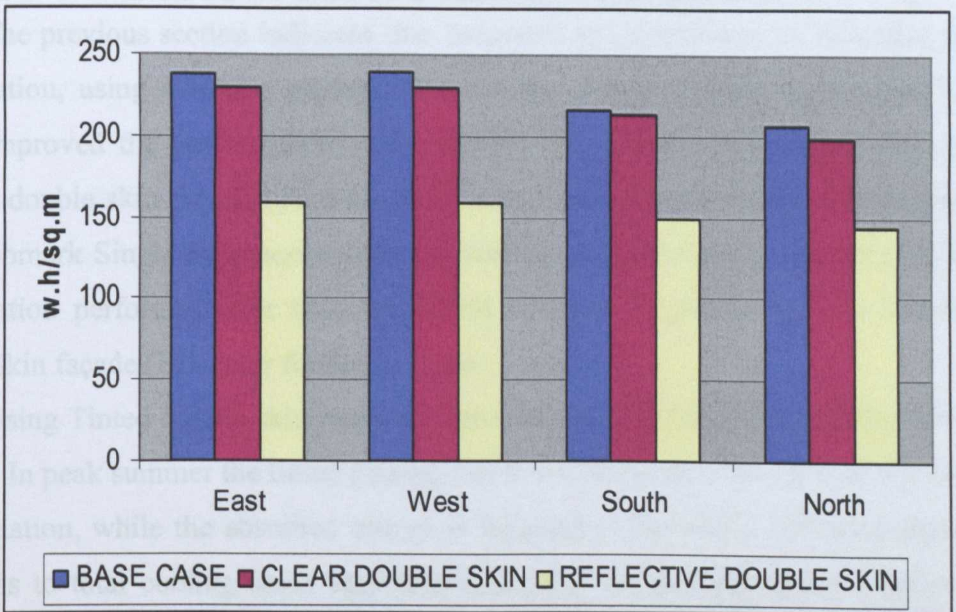


Figure 38: Impact of using reflective glazing of the Double Skin Facade on peak Summer total cooling loads

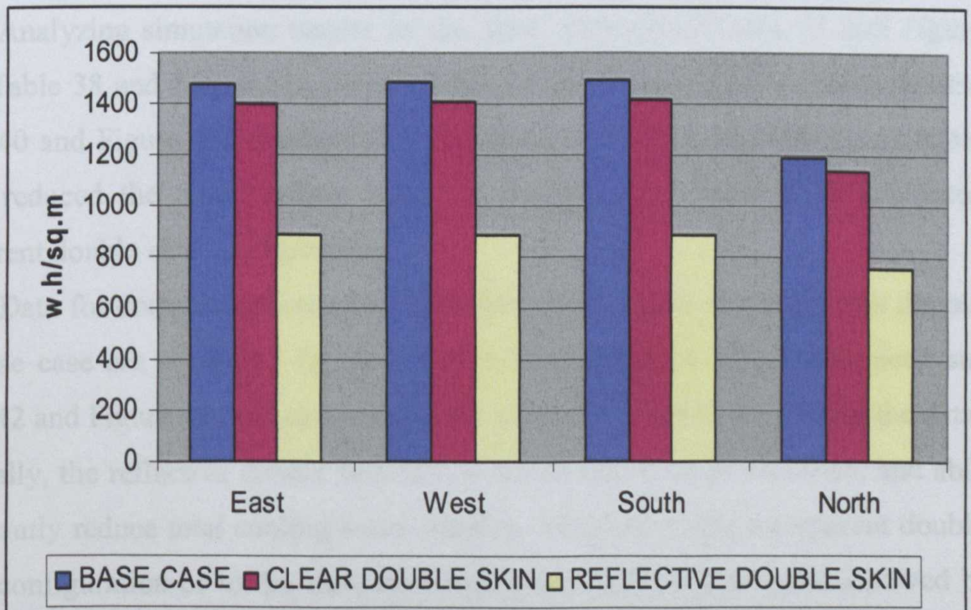


Figure 39: Impact of using reflective glazing of the Double Skin Facade on annual total cooling loads

8.6 A Benchmark Double Skin or a Benchmark Single Skin :

The previous section indicated that compared to a transparent double skin façade configuration, using selective glazing types on the exterior surface of the double skin façade improved the performance of the double skin façade. The performance of the selective double skin façade (Tinted and reflective double skin facades) is compared to the Benchmark Single Skin performance to find out which selective double skin façade configuration performs better than the (BSS) and can be promoted to a Benchmark Double Skin façade (BDS) for further analysis.

Using Tinted double skin increased the total cooling loads in winter by 35% than the BSS. In peak summer the tinted glazing due to its ability to reflect part of the incident solar radiation, while the absorbed energy is released to the cavity indicated significant reductions to total cooling loads approximately 12% for all orientations. However the increase in peak winter total cooling loads did not offset the peak summer cooling load reductions. Annual total cooling loads indicate on average 12% reductions on all façade orientations.

On monthly basis, simulation results for using selective double skin façade configuration are presented for the four façade orientations in tabular and graphical forms. Analyzing simulation results for the East orientation (Table 37 and Figure 40), West (Table 38 and Figure 41), South (Table 39 and Figure 42), and North orientations (Table 40 and Figure 43) indicates that compared to the BSS the reflective double skin façade reduced the total cooling loads on monthly basis better than the tinted and transparent double skin configurations.

Data for comparing tinted and reflective double skins to transparent double skin and Base case are presented for peak winter (Table 41 and Figure 44), peak summer (Table 42 and Figure 45) and annually (Table 43 and Figure 46). Analyzing the data cross sectionally, the reflective double skin façade stands out in its performance and ability to significantly reduce total cooling loads whether compared to the transparent double skin façade configuration or to the Base case configuration. The reductions achieved by this façade configurations lead to a significant downsizing of cooling equipment and the space needed to house these equipment within the building. There are two major economic gains in this case, apart from continuous energy savings and reduced electricity bills; using less space for equipment leaves more space for rental as office space.

Comparing the performance of the reflective double skin configuration to BSS, the reflective double skin is predicted to decrease total annual cooling loads by approximately 30% reductions in cooling loads.

In conclusion, due to its performance the reflective double skin façade will be considered the Benchmark Double skin in further analysis.

Table 37: Comparison between Benchmark Single Skin (BSS) and Selective Double skin on the East Orientation

East Orientation Total Cooling loads (W.h/m^2)

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
January	15	6	14	9	5
February	30	18	28	19	11
March	66	50	63	47	31
April	105	87	98	75	51
May	148	129	138	111	81
June	184	165	173	142	106
July	230	212	219	187	150
August	238	220	229	196	159
September	196	179	186	158	126
October	158	143	150	127	101
November	83	72	79	65	51
December	28	19	26	19	13
Total	1480	1299	1401	1155	885

Table 38: Comparison between benchmark Single Skin and Selective Double Skin on the West Orientation

West Orientation Total Cooling Loads (W.h/m^2)

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
January	17	8	14	10	6
February	31	19	29	20	11
March	68	51	64	47	31
April	106	87	100	76	51
May	150	130	142	113	81
June	185	172	176	143	107
July	232	213	219	188	151
August	239	220	230	196	159
September	194	177	185	157	124
October	159	143	152	127	101
November	82	72	76	65	51
December	28	19	26	19	13
Total	1490	1311	1413	1161	886

Table 39: Comparison between Benchmark Single Skin (BSS) and Selective Double skin on the South Orientation

South Orientation Total Cooling Loads (W.h/m^2)

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
January	47	25	40	26	15
February	52	32	46	30	18
March	72	55	68	51	33
April	87	77	84	65	48
May	120	112	116	95	70
June	153	145	144	122	98
July	201	193	193	168	135
August	216	206	213	176	150
September	194	177	186	155	124
October	179	156	168	142	110
November	115	92	104	86	62
December	61	39	55	44	23
Total	1498	1311	1417	1160	886

Table 40: Comparison between Optimized Single Skin and Selective Double Skin on the North Orientation

North Orientation Total cooling Loads (W.h/m^2)

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
January	2	-1	5	3	2
February	11	8	13	10	4
March	39	34	38	30	21
April	73	67	75	56	39
May	123	112	113	85	69
June	159	149	149	127	100
July	203	195	193	157	137
August	207	200	199	162	144
September	165	159	157	125	112
October	132	127	126	101	89
November	65	62	63	55	43
December	14	11	15	10	7
Total	1192	1121	1151	915	767

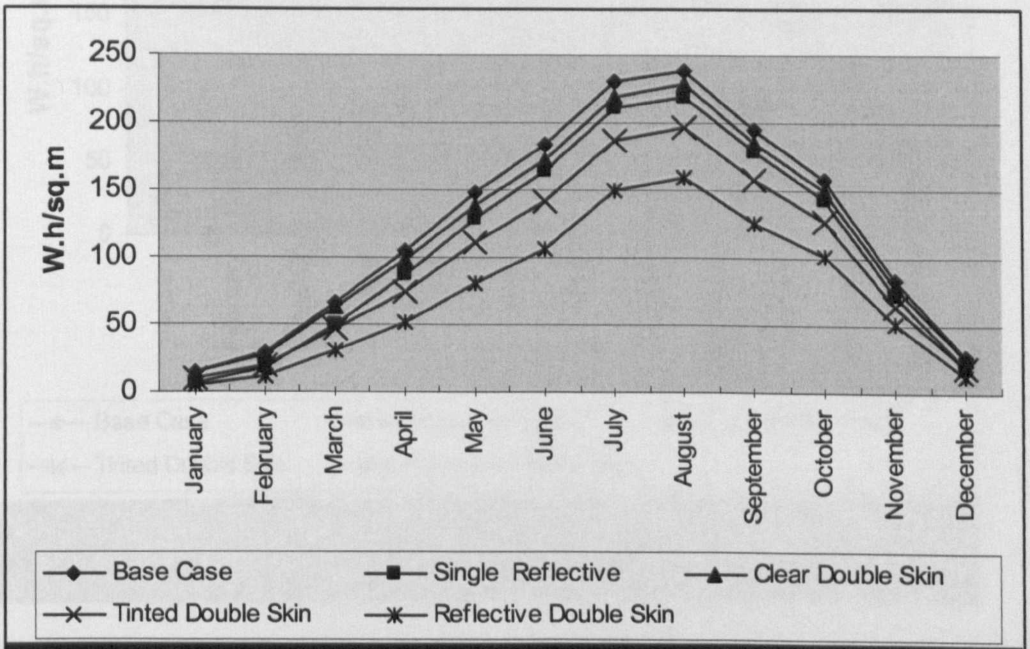


Figure 40: Comparison between Benchmark Single Skin and Selective Double Skin on the East Orientation

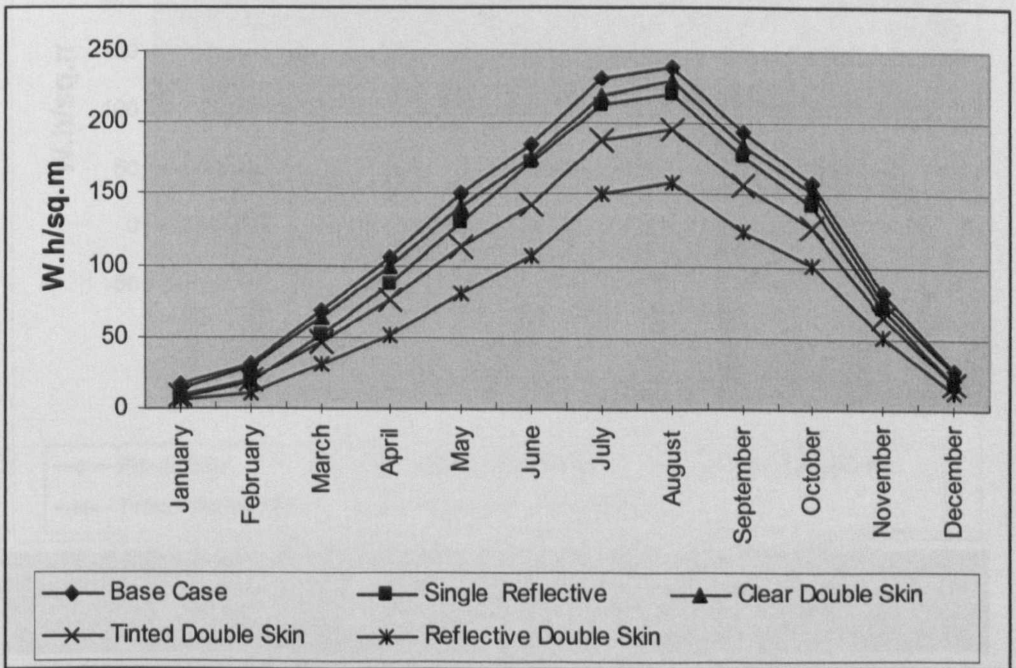


Figure 41: Comparison between Optimized Single Skin and Selective Double Skin on the West Orientation

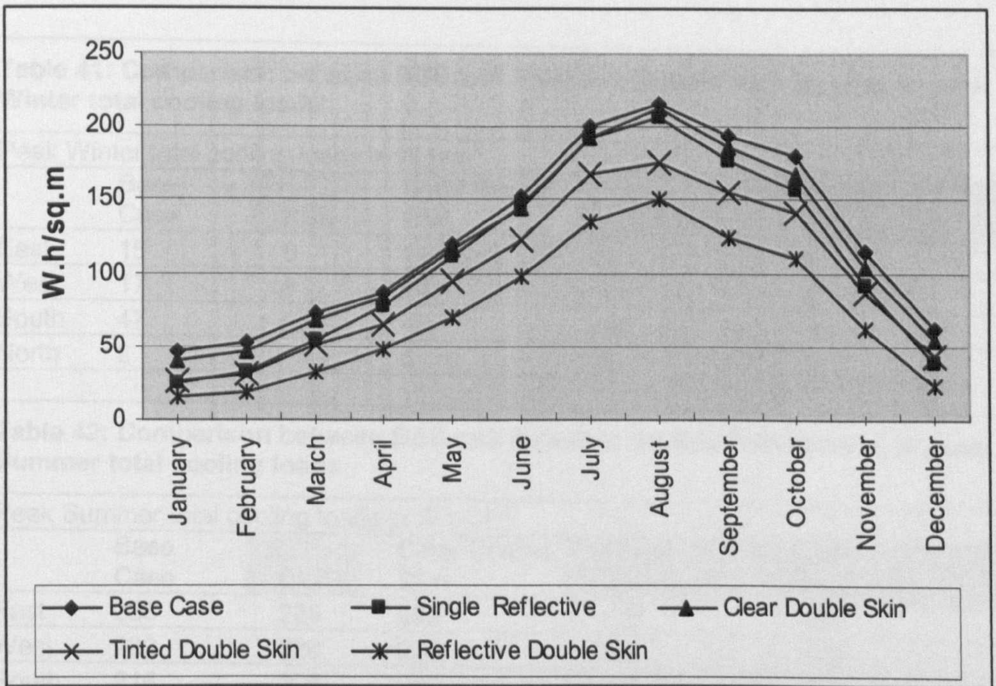


Figure 42: Comparison between Optimized Single Skin and Selective Double Skin on the South Orientation

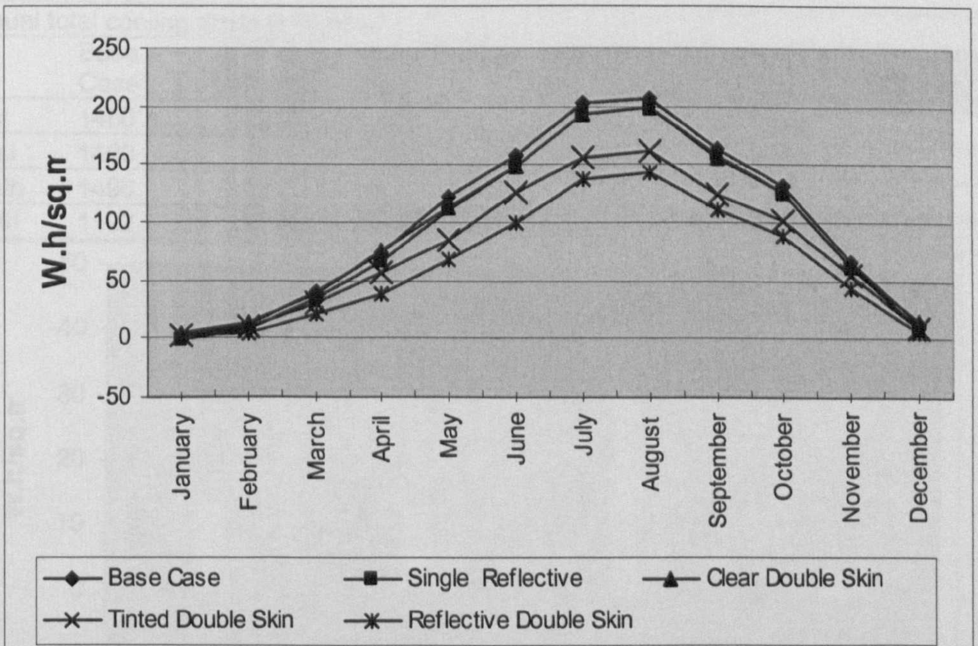


Figure 43: Comparison between Optimized Single Skin and Selective Double Skin on the North Orientation

Table 41: Comparison between BSS and Selective Double Skin facades in peak Winter total cooling loads

Peak Winter total cooling loads in W.h/m^2

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
East	15	6	14	9	5
West	17	8	14	10	6
South	47	25	40	26	15
North	2	-1	5	3	2

Table 42: Comparison between BSS and Selective Double Skin facades in peak Summer total cooling loads

Peak Summer total cooling loads in W.h/ m^2

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
East	238	220	229	196	159
West	239	220	230	196	159
South	216	206	213	176	150
North	207	200	199	162	144

Table 43: Comparison between BSS and Selective Double Skin facades on Annual total cooling loads

Annual total cooling loads in W.h/ m^2

	Base Case	BSS	Clear Double Skin	Tinted Double Skin	Reflective Double Skin
East	1480	1299	1401	1155	885
West	1490	1311	1413	1161	886
South	1498	1311	1417	1164	886
North	1192	1121	1142	921	767

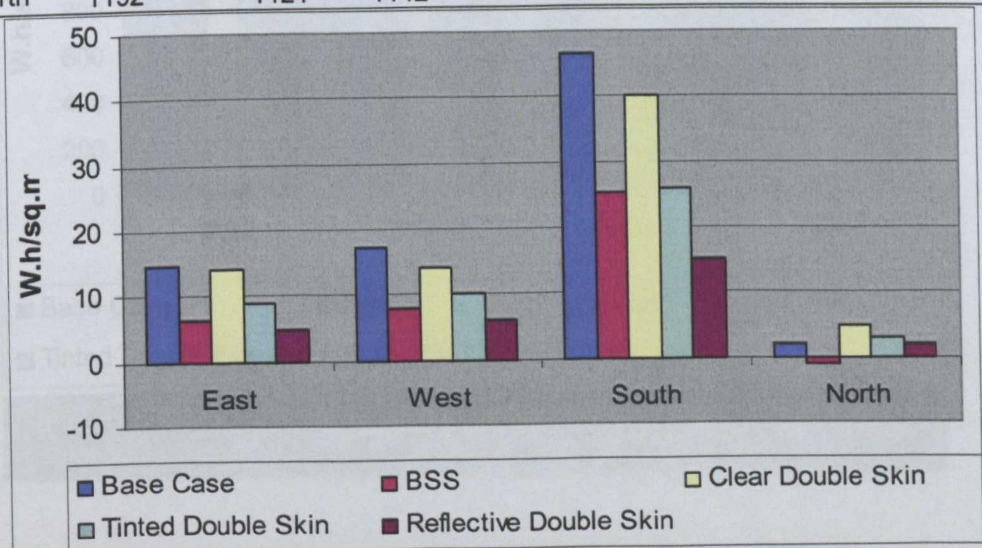


Figure 44: Comparison between BSS and Selective Double Skin in peak Winter total cooling loads.

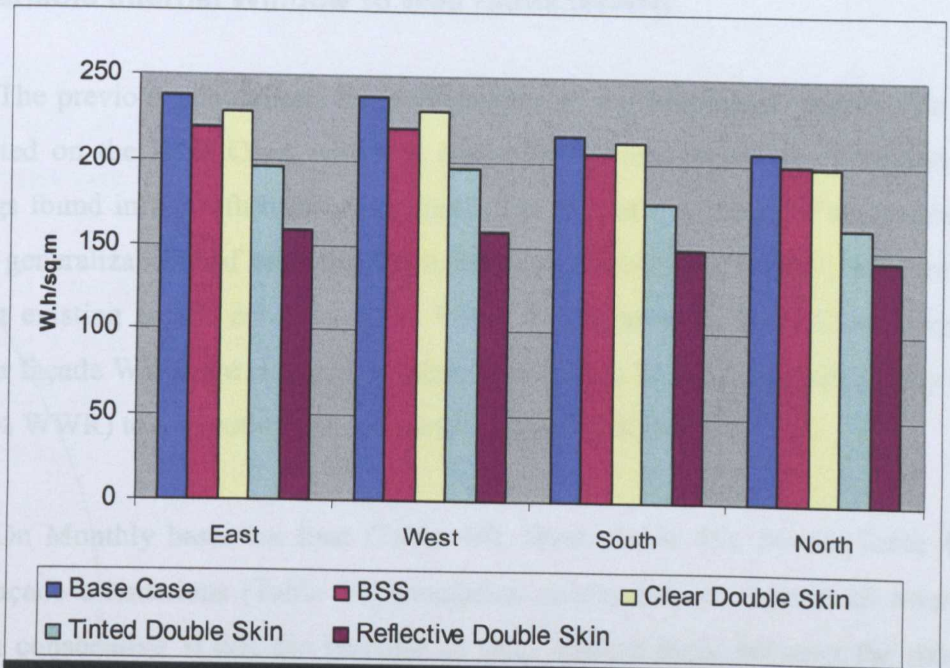


Figure 45: Comparison between BSS and selective double skin in peak Summer total cooling loads

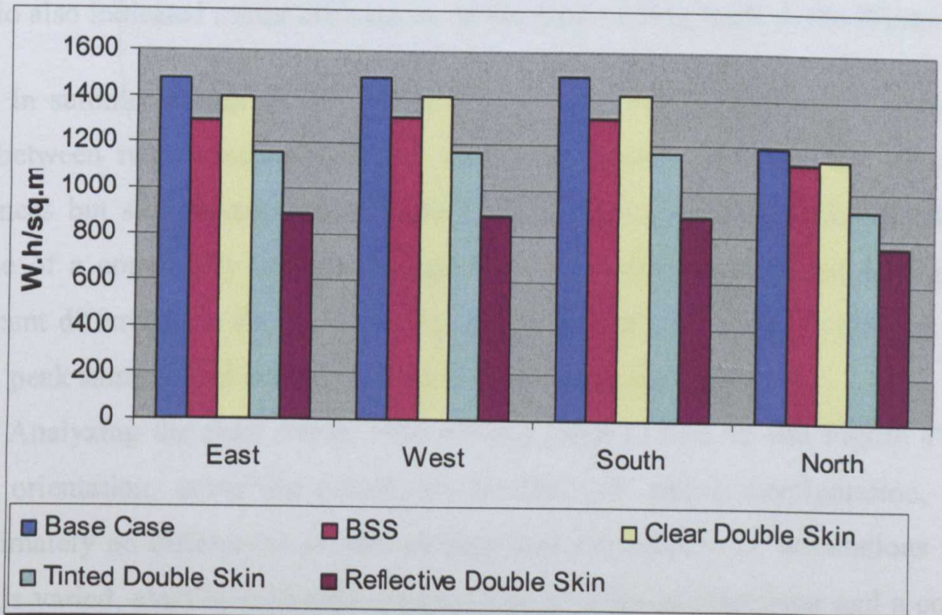


Figure 46: Comparison between BSS and selective double skin on annual total cooling loads

8.7 Case 5: The impact of The benchmark Double Skin Façade (BDS) on variable internal Window to Wall ratios.(WWR)

The previous simulations the performance of the benchmark double skin façade was tested on the Base Case, which is equivalent to one façade configuration of the buildings found in the refurbishment sample. The aim of this group of simulations is to test the generalizability of applying the benchmark double skin façade configuration on different existing façade configurations. While maintaining the Base Case morphology the outer façade WWR are changed in increments from a hypothetical completely opaque wall (0% WWR) to a hypothetical completely glazed wall (80%).

On Monthly basis, on East (Table 44), West (Table 45), South (Table 46) and North façade orientations (Table 47) simulation results indicate that on all orientations between consecutive WWR the increase in total cooling loads between the months of October to February was insignificant. Looking at the results cross-sectionally comparing the two extremes of the hypothetical completely opaque and the completely glazed scenario also indicated minor differences on the total cooling loads in the Winter month .

In summer month on all orientations, the differences between the total cooling loads between two consecutive WWR were more pronounced than the winter month differences but still remains insignificant. Unless an inner WWR is increased from an extreme of a completely opaque configuration to a completely glazed configuration a significant difference in the total cooling load is realized. To quantify changes the peak winter, peak summer and annual total cooling loads are discussed.

Analyzing the peak winter total cooling loads (Table 48 and Figure 47), on all façade orientation, using the benchmark double skin façade configuration, indicates approximately no differences in total cooling load demands in all orientations when the WWR is varied, even between the extreme case of a completely inner and a completely glazed inner façade. It may be concluded that in peak winter the benchmark double skin façade was able to control heat transfer and render all changes of WWR on the inner wall ineffective in increasing the total cooling loads.

In Peak summer month (Table 49 and Figure 48), the increase in total cooling loads between each WWR and its consecutive higher WWR is insignificant. Only when the extreme cases of the hypothetically opaque and the completely glazed inner facades are compared do the differences in total cooling load become between 7-8% according to façade orientation.

On Annual basis (Table 50 and Figure 49), the cumulative effect of the summer and winter month, confirm the previous findings that unless the two hypothetical cases of a completely opaque to a completely glazed inner façade do significant differences occur according to the inner WWR. The results indicate that the Benchmark Double skin façade predominantly performs better than the benchmark Single Skin façade.

In concluded the benchmark double skin façade predictions on its performance in reducing total cooling loads year round on the base case may be extended to be used on the different existing facades with various window to wall ratios in the refurbishment phase without energy penalties. In cases where there is a need to extend the view out, if the benchmark double skin façade configuration is used then the inner WWR may be enlarged without energy penalties.

Table 44: Using BDS on variable internal WWR on the East Orientation

East Orientation (Total cooling loads in W.h/m^2)

	Inner Opaque	Inner 10% CL	Inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
January	5	5	5	5	5	5	5
February	10	11	11	11	11	11	12
March	29	29	30	31	31	31	32
April	47	49	50	51	51	52	53
May	75	78	80	81	81	82	83
June	99	102	105	105	106	107	108
July	141	145	147	148	150	151	151
August	149	154	157	158	159	160	160
September	118	122	123	124	126	127	127
October	95	97	99	100	101	101	102
November	48	49	50	51	51	51	51
December	12	12	13	13	13	13	13
Total	828	852	871	879	885	892	898

Table 45: Using BDS on variable internal WWR on the West Orientation

West Orientation (Total Cooling Loads in W.h/ m^2)

	Inner Opaque	Inner 10% CL	Inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
January	5	5	6	6	6	6	6
February	10	11	11	11	11	12	12
March	29	30	30	31	31	32	32
April	48	49	50	50	51	52	53
May	76	77	80	82	81	82	84
June	100	103	106	107	107	108	109
July	141	145	148	149	151	151	151
August	149	154	155	156	159	160	160
September	118	120	122	123	124	126	127
October	95	98	100	101	101	102	102
November	48	49	50	51	51	51	52
December	12	13	13	13	13	13	13
Total	831	854	871	880	886	895	901

Table 46: Using BDS on variable internal WWR on the South Facade

South Orientation (Total Cooling Loads W.h/ m^2)

	Inner Opaque	Inner 10% CL	Inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
January	14	15	15	15	15	15	15
February	15	16	17	17	18	19	19
March	31	32	33	33	33	34	35
April	44	44	46	47	48	48	49
May	61	66	68	70	70	72	73
June	94	95	97	97	98	101	102
July	127	129	131	133	135	136	136
August	141	145	148	149	150	152	153
September	122	124	124	124	124	125	125
October	104	106	108	110	110	111	111
November	59	61	62	62	62	62	62
December	21	21	22	23	23	23	23
Total	833	854	871	880	886	898	904

Table 47: Using BDS on variable internal WWR on the North Facade

North Orientation Total Cooling Loads (W.h/ m^2)

	Inner Opaque	Inner 10% CL	Inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
January	2	2	2	2	2	2	2
February	3	3	4	4	4	4	4
March	19	20	21	21	21	21	22
April	35	37	39	39	39	40	41
May	64	67	68	69	69	71	72
June	91	94	97	98	100	101	102
July	128	132	135	137	137	138	138
August	135	139	142	142	144	145	146
September	104	108	110	112	112	113	113
October	83	86	88	89	89	90	91
November	39	40	42	43	43	43	43
December	6	7	7	7	7	7	7
Total	709	735	755	761	767	775	781

Table 48: Using BDS on variable WWR in Peak Winter

Peak Winter Total Cooling Loads in W.h/m^2

	Inner Opaque	Inner 10% CL	Inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
East	5	5	5	5	5	5	5
West	5	5	6	6	6	6	6
South	14	14	15	15	15	15	15
North	2	2	2	2	2	2	2

Table 49: Using BDS on variable WWR in peak Summer

Peak Summer Total Cooling Loads in W.h/m^2

	Inner Opaque	Inner 10% CL	inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
East	149	154	157	158	159	160	160
West	149	154	155	156	159	160	160
South	141	145	148	149	150	152	153
North	135	139	142	142	144	145	146

Table 50: Using BDS on variable WWR on annual basis

Annual Total Cooling Loads in W.h/m^2

	Inner Opaque	Inner 10% CL	inner 20% CL	Inner 30% CL	Inner 40% CL BDS	Inner 60% CL	Inner 80% CL
East	828	852	871	879	885	892	898
West	831	854	871	880	886	895	901
South	833	854	871	880	886	898	904
North	709	735	755	761	767	775	781

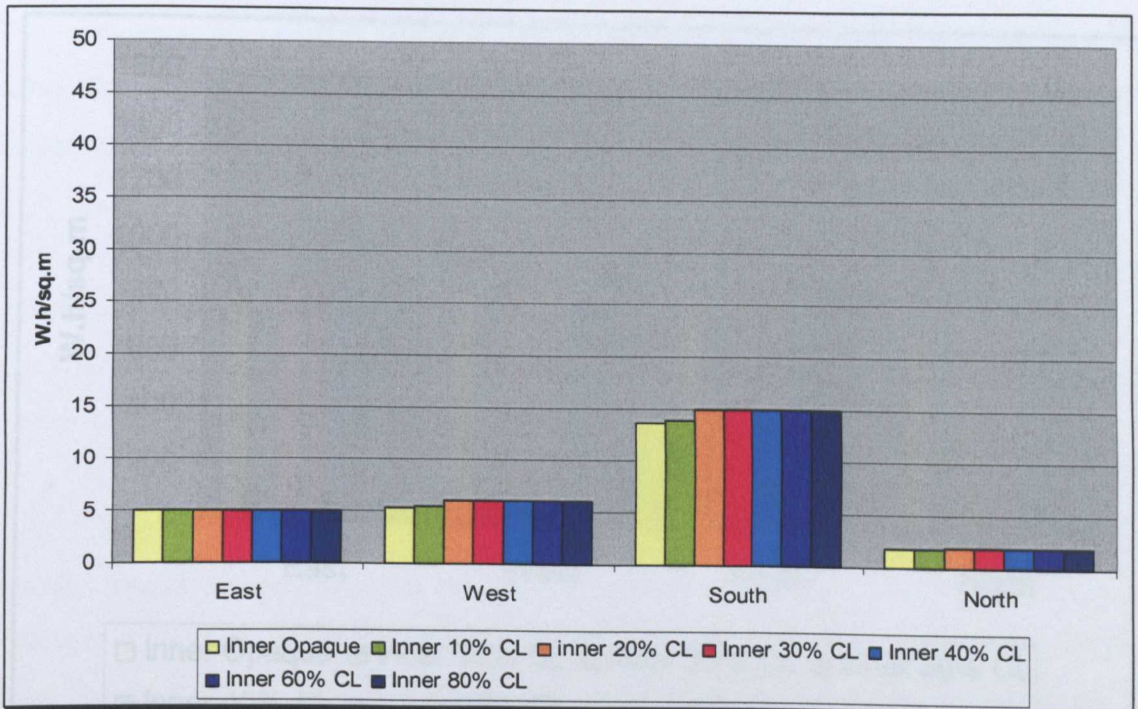


Figure 47: Impact of BDS on Different Inner WWR on Peak Winter Total Cooling loads

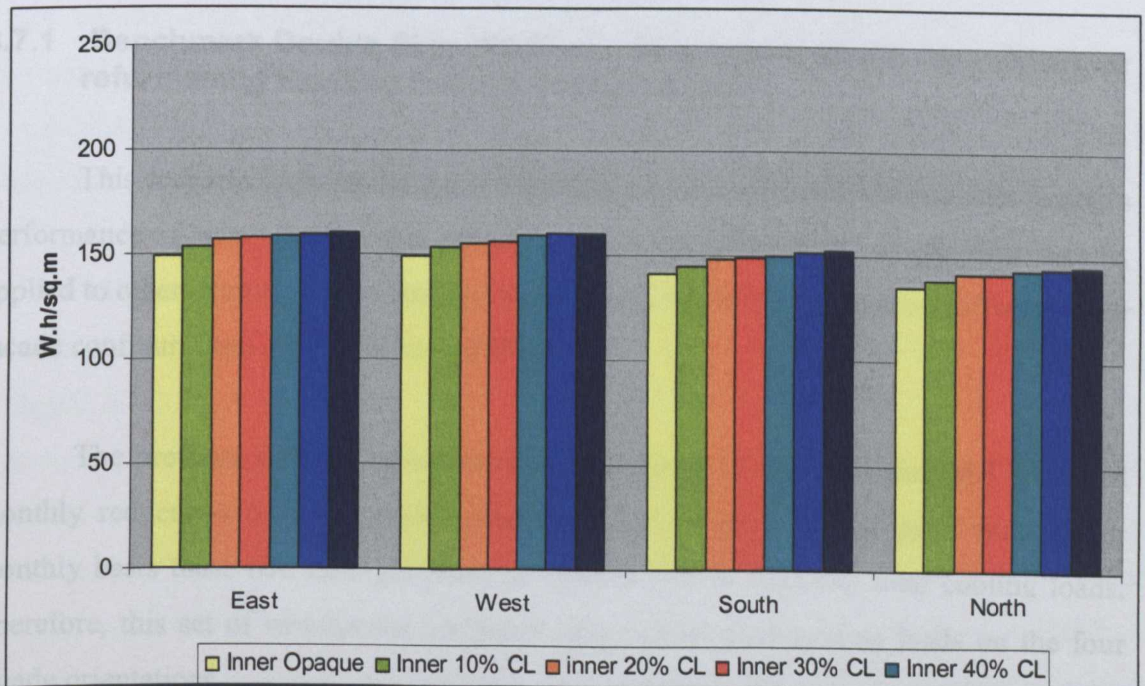


Figure 48: Impact of BDS on different inner WWR on Peak Summer total Cooling loads

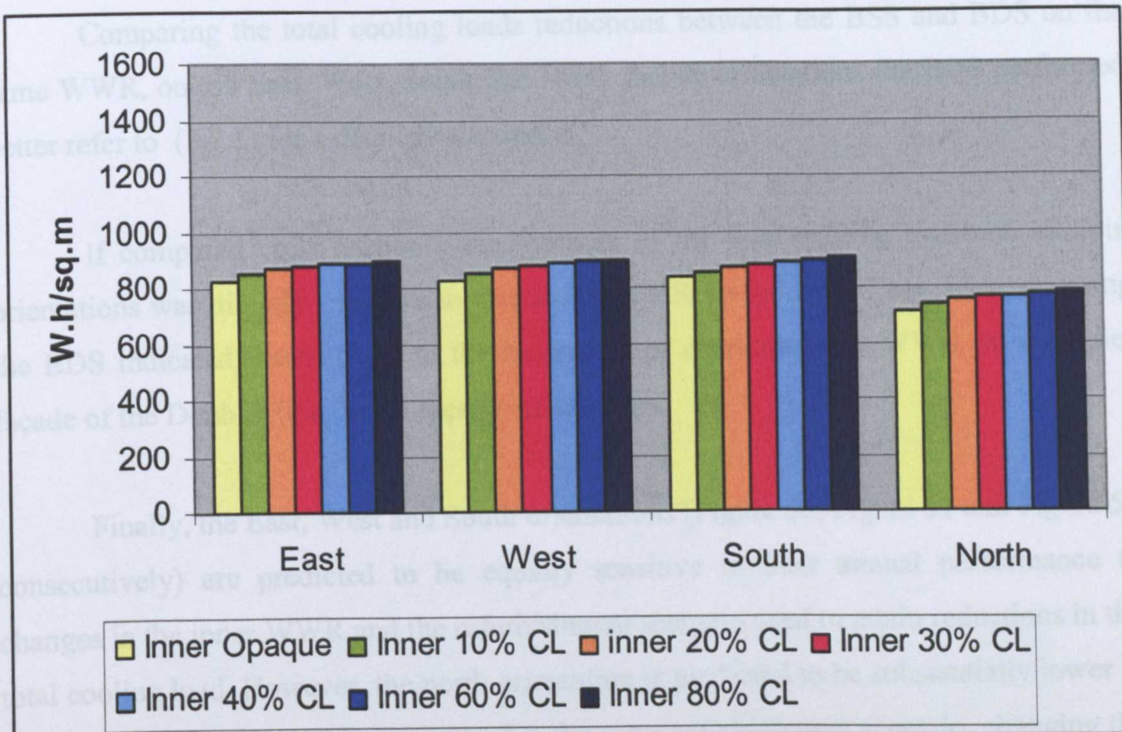


Figure 49: Impact of BDS on Different Inner WWR on Annual Total Cooling Loads

8.7.1 Benchmark Double Skin (BDS) or a Benchmark Single Skin (BSS) for refurbishing Existing Façade Configurations

This scenario looks at the generalizability of the benchmark double skin façade's performance if compared to the performance of the benchmark single skin façade, applied to other existing façade configurations. This is achieved by testing different inner façade configurations WWR between 20% to 40%.

The previous data analysis indicated that using the BSS and the DSS indicated monthly reductions to total cooling loads whether on peak winter, peak summer, or monthly basis these two configurations performed best in reducing total cooling loads. Therefore, this set of simulations compares only annual total cooling loads on the four façade orientations.

Comparing the total cooling loads reductions between the BSS and BDS on the same WWR, on the East, West, South and North façade orientations the BDS performed better refer to (8.7.1) for a detailed discussion.

If compared cross-sectionly the increase of the total cooling loads on all four orientations was directly sensitive to increasing WWR on the Base Case, however using the BDS indicated insensitivity to the increasing or decreasing the WWR on the inner façade of the Double Skin for all façade orientations.

Finally, the East, West and South orientations (Figure 50, Figure 51 and Figure 52 consecutively) are predicted to be equally sensitive in their annual performance to changes in the inner WWR and the refurbishment scenario used to attain reductions in the total cooling load. However, the north orientation is predicted to be substantially lower in its annual total cooling load demands. For the same refurbishment scenario, changing the WWR indicated that the North façade (Figure 53) is less sensitive to this variable. The BDS remains the refurbishment option that substantially lowers this orientations annual total cooling load demands.The relationship between the WWR and total cooling load demand is a linear relationship. For higher WWR ratios, the three lines of the Base Case, Benchmark single skin and Benchmark double skin may be extrapolated to compare their performance on higher WWR than found in the façade refurbishment sample.

Figure , extends the comparison between BSS and BDS on a range of WWR ranging between a hypothetically opaque façade to a hypothetically completely glazed façade. Results indicate a linear relation between WWR of the façade technology used and total cooling loads. It is important to note that results for the BDS retain the fully glazed reflective surface on the exterior while the WWR are only changed on the interior façade. Results indicate the superior performance of the BDS compared to the BSS even if glazing ratios are increased to 80%. This indicates that the BDS offers opportunities to increase the view out on all levels of façade configurations (WWR) without energy penalties in a hot arid climate.

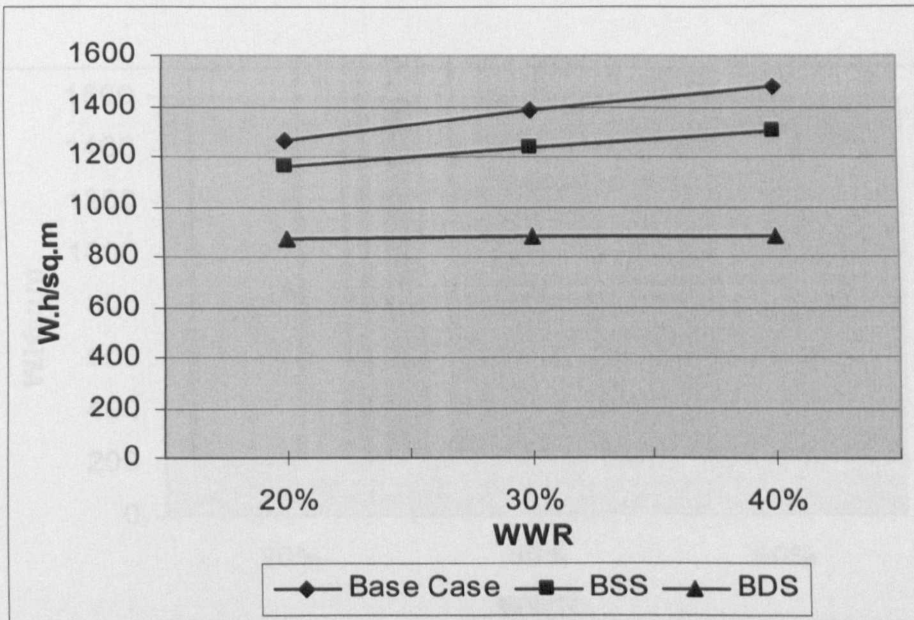


Figure 50: Comparison between BSS and BDS on various WWR on the East orientation

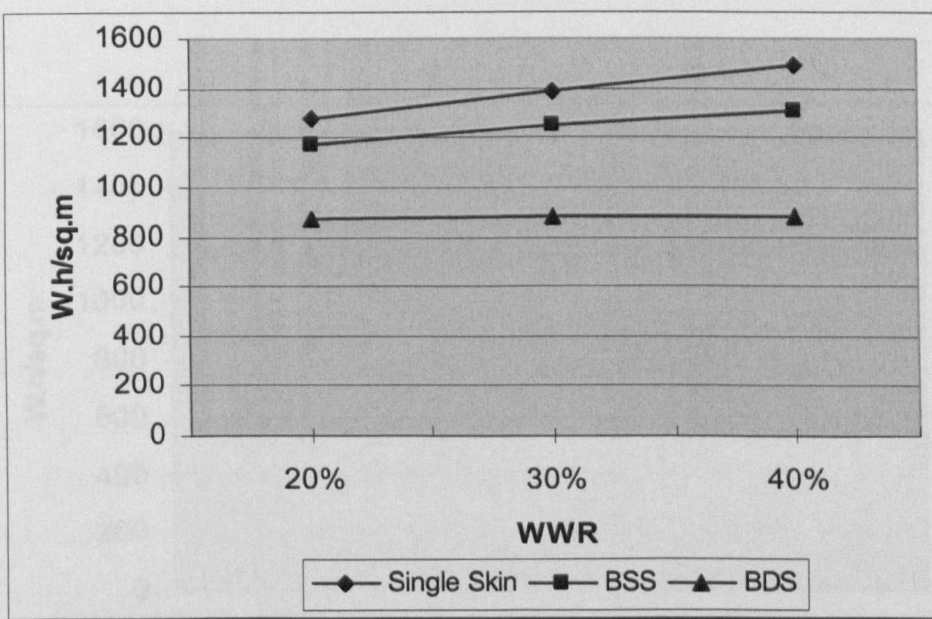


Figure 51: Comparison of BSS and BDS on various WWR on the West orientation

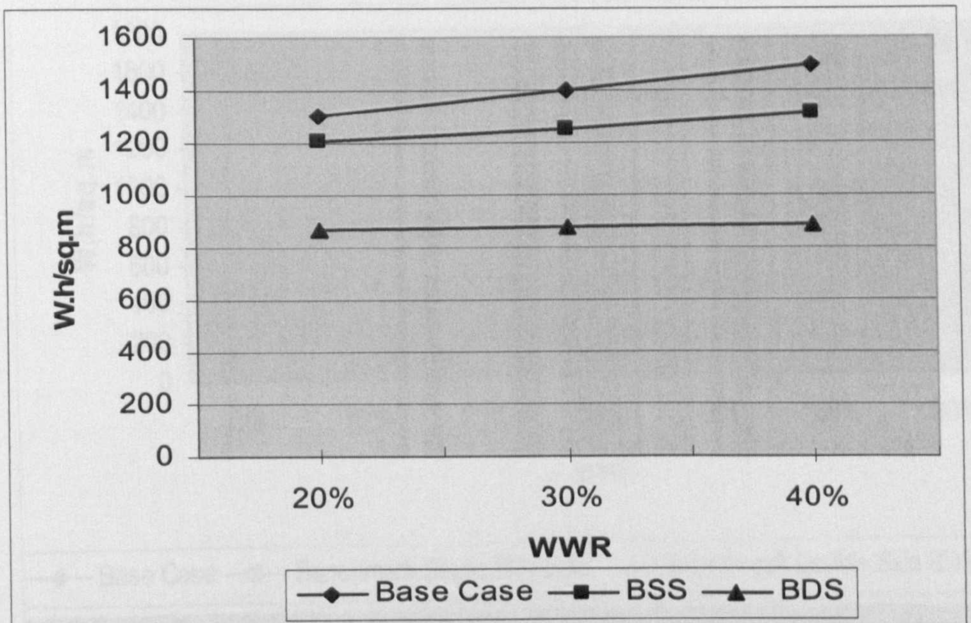


Figure 52: Comparison between BSS and BDS on various WWR on the South orientation

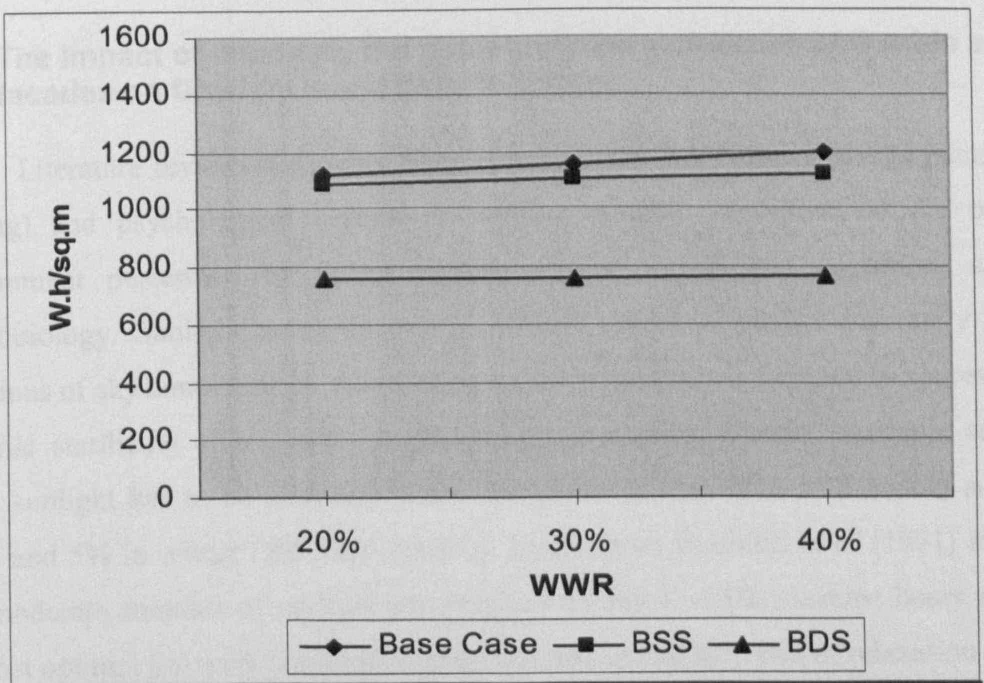


Figure 53: Comparison between BSS and BDS on the North orientation

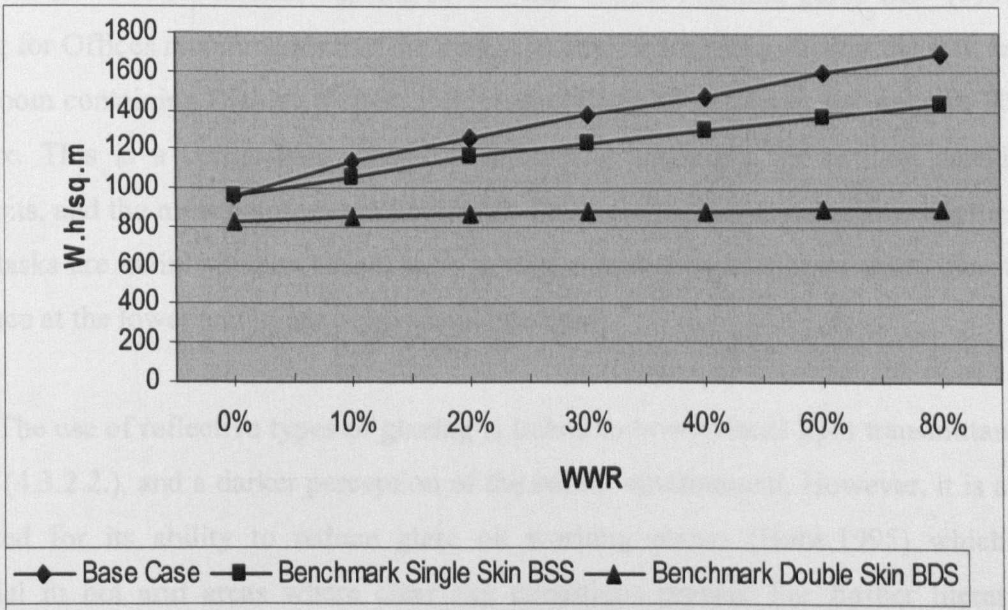


Figure 54: Extended Comparison between BSS and BDS on WWR on the East Oriented facades

8.8 The impact of changing the glazing optical properties of Double skin facades on Daylight availability in Offices

Literature review in Chapter Four discussed the link between the physical (task lighting) and psychological aspects of lighting namely; perception of the outdoor environment perception of indoor spaces; arousal, mood and cognition, and on chronobiology. Sunlight penetration is a difficult aspect to predict accurately due to variations of sky conditions. Although direct solar penetration is required in spaces for its hygienic sterilizing effects and for psychological reasons, British Standards suggests direct sunlight has to be admitted in the workplace at least 25% of probable sunshine hours and 5% in winter (BS 8206-2:1992). Research by Boubikri *et al* (1991) suggests that moderate amounts of sunlight penetration between 15-25% sunshine hours seem to be most optimal for tasks requiring high concentration and intervals of relaxation such as office work. Very large sunlight penetration causes opposite feelings that are low pressure and high arousal causing the occupant to desire to avoid such places.

CIBSE code for interior lighting (1996) and CIBSE Lighting guide LG7 (1993): Lighting for Offices recommends that the design maintained luminance over the task area in any room containing Display System Equipment (DSE) should be in the range of 300-500 Lux. This is a compromise between luminance necessary for reading working documents, and the most comfortable luminance for operating display system equipment. Where tasks are mainly screen based, such as data retrieval or telephone sales, then the luminance at the lower end of the range should be used.

The use of reflective types of glazing is linked to lower visual light transmittance, refer to (4.3.2.2.), and a darker perception of the indoor environment. However, it is also accredited for its ability to reduce glare on working planes (Hube,1995) which is beneficial in hot arid areas where clear sky conditions prevail. For further literature review and discussion, refer to Chapter 4 section 4.3.2.

To study the availability of day lighting and its qualities in summer, the Base Case, the Benchmark Single Skin and the Benchmark double skin are compared during direct and diffuse solar radiation hours (Figure 55). Simulations were carried out using Radiance software, which is a sub routine incorporated into the IES Software (APACHE is part of the IES suit)

In summer, during direct solar radiation hours and in a clear sky situation, the Base Case indicated that due to direct solar radiation on the West façade that almost 50% of the floor area would experience higher than acceptable day lighting levels reaching 950 Lux at worktop levels (75cm from floor level). While the East façade of the Base case indicated spots of high day lighting levels which may cause glare. This is expected due to the weak ability of clear glazing to control direct solar transmission (which includes the visible light range of wavelengths). Higher than needed daylight levels although necessary for short periods of time to alleviate mood but longer exposure leads to annoyance and thus drawing of curtains excluding the view out.

The Benchmark Single Skin with its reflective single glazing on fenestration areas decreased lighting levels on both East and West orientations in summer. However, simulation results indicate high daylight levels on the area adjacent to the windows in case of direct solar radiation falling on the façade (950 Lux). Diffuse day light hours simulated on the East façade indicates variable but uniform levels of daylight suitable for office work.

The Benchmark double skin façade with its exterior leaf being of reflective glazing and separated from the inner leaf by a meter wide gap, led to further decrease in daylight levels than the Benchmark Single Skin. In diffuse daylight hours in summer, daylight levels did not exceed 650 Lux in the area adjacent to windows with Lux levels falling to 250 Lux at the depth of the room.

During direct solar radiation hours in summer day lighting levels raged between 950 Lux to 250 Lux at depth of room.

In winter (Figure 56), simulation results were carried out on the three façade configurations to test daylight levels during diffuse and direct solar radiation hours.

The Base case indicated that during direct solar radiation in clear sky conditions in winter high day lighting Lux levels of 950 Lux are predicted to cover around third of the working planes in the room. Diffuse day lighting levels ranged between 750-350 Lux which according to daylight levels required for office work would have created a good natural day lit area. However the energy penalty may contradict with the use of clear glazing for daylight in this case.

The Benchmark Single Skin indicated high day light levels in areas adjacent to windows ranging between 950-450 Lux. However a more uniform day lit area is created during diffuse solar radiation hours. This indicates that the benchmark single skin is a reasonable compromise between energy efficiency and daylight levels to using clear skin.

The Benchmark Double Skin Façade indicated a superior capability in controlling daylight levels in winter during direct solar radiation hours with room day lighting levels ranging between 850-250 Lux. But during diffuse solar radiation hours a dark environment is predicted with lighting levels falling below those needed to carry out work on visual display screens. This later effect may necessitate the use of electrical lighting to top up lighting levels in the space. Although in the later scenario the Double Skin Façade performed the worse in comparison to other façade configurations it maybe argued that direct solar radiation hours are prolonged in hot arid areas and the case of a diffuse winter daylight condition is a short duration that lasts between December and February and therefore the effect of double skin facades on reducing cooling loads is not offset by using electrical lighting in the winter period. However this conclusion needs further studies in later research.

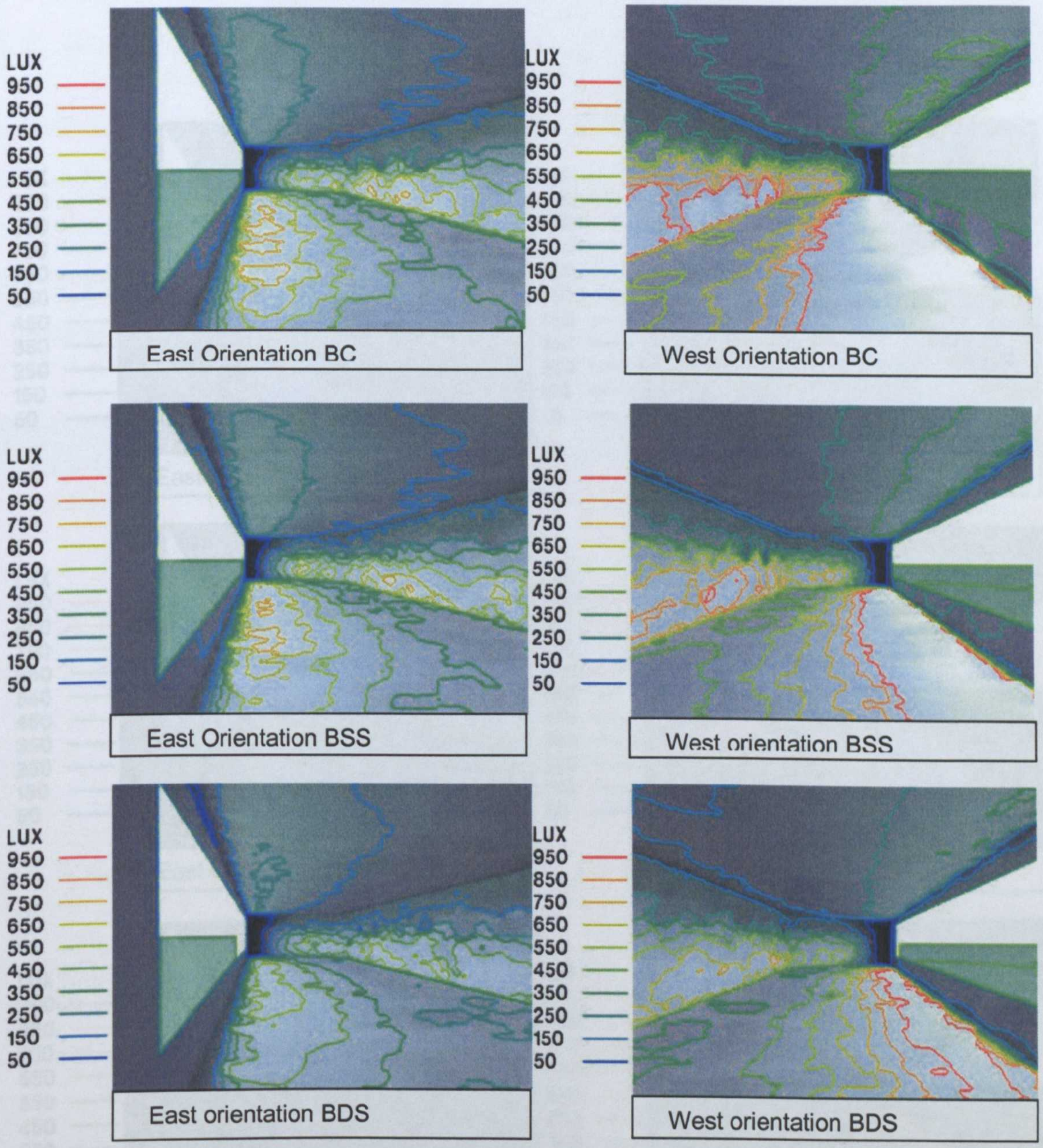


Figure 55: Comparison of daylight availability under Clear sky conditions in a Summer month (2nd August at 2p.m.)

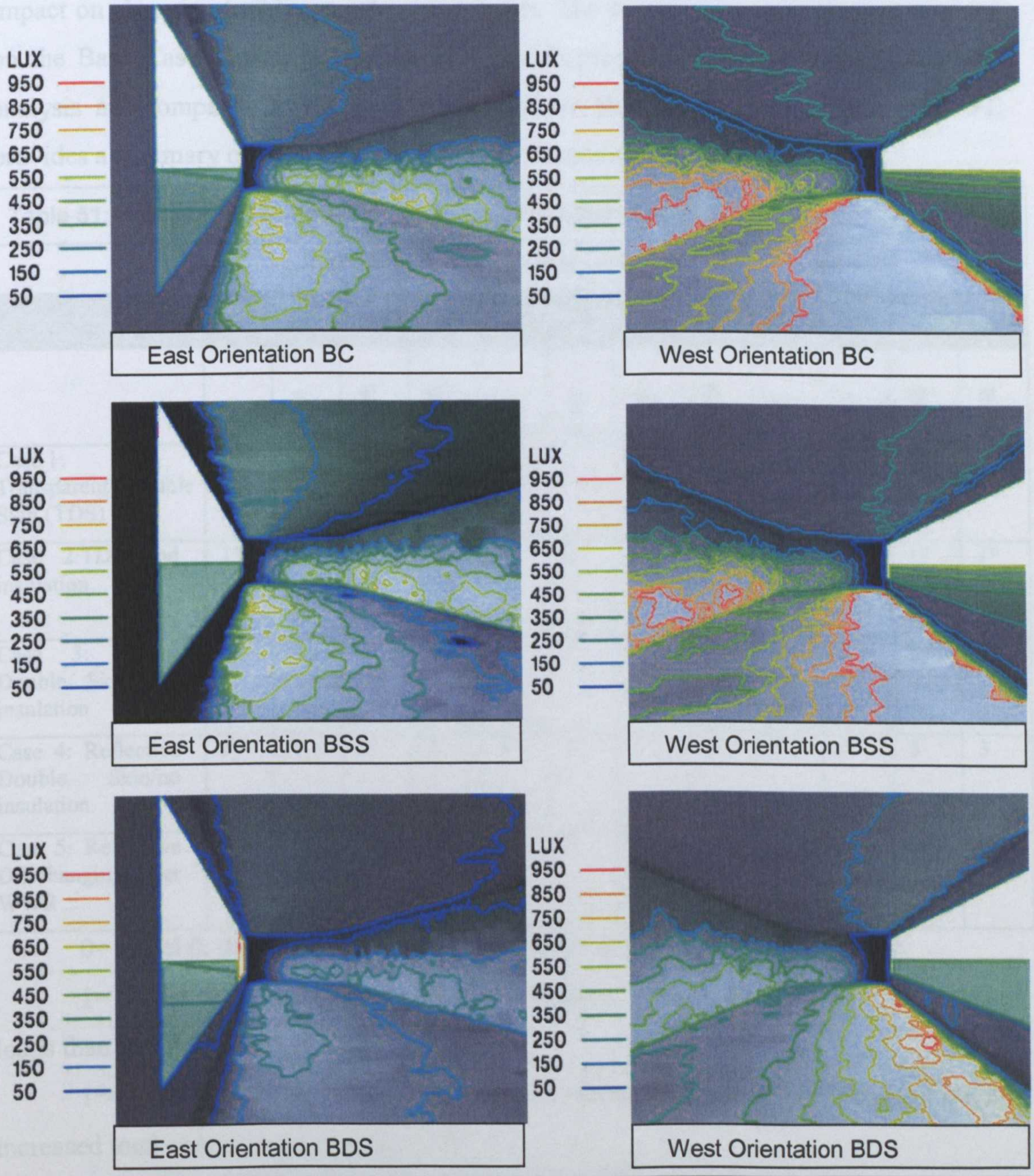


Figure 56: Comparison between daylight availability under clear sky conditions in a winter month (14th of January at 2p.m.)

8.9 Conclusions:

A double skin façade configuration was tested on the base case to predict its impact on changing building total cooling loads. The double skin configuration is added on the Base Case constructed in the previous chapter. Building Thermal and daylight analysis are compared to the performance of the Benchmark Single skin. Table 51, provides a summary of the results predicted by the simulation software.

Table 51: Summary of Double Skin Facades Simulation Analysis

	Impact on Total Cooling Loads W.h/m^2											
	Summer				Winter				Annual			
	East	West	South	North	East	West	South	North	East	West	South	North
Case 1: Transparent Double Skin (TDS)	1	1	1	1	1	1	1	1	1	1	1	1
Case 2:TDS and insulation	1*	1*	1*	1*	0	0	0	0	1*	1*	1*	1*
Case 3: Tinted Double Skin/ no insulation	2	2	1	2	1	1	2	1	2	2	2	2
Case 4: Reflective Double Skin/no insulation	3	3	3	3	3	3	3	3	3	3	3	3
Case 5: Reflective DS changing inner WWR	3	3	3	3	3	3	3	3	3	3	3	3

0= Level 0: denotes an increase in total cooling loads than the Base Case

1= Level 1: denotes an insignificant decrease of less than 5% in total cooling loads than the Base Case

1*=Level 1: denotes a reduction in total cooling loads than the Base Case but an increased total cooling load than the TDS.

2= Level 2: denotes a significant reduction in total cooling loads more than the Benchmark Single Skin

3= Level 3: denotes the double skin façade configuration with most impact on reducing total cooling loads than the Base Case. Thus is called the 'Benchmark Double Skin' façade configuration.

The previous analysis of Double skin façade configurations (Case1), indicates whether on peak summer, peak winter or annual consumption levels that the transparent double skin façade had an insignificant impact on reducing total cooling loads than the Base Case

Adding external insulation to the original single skin (facing the cavity) in Case 2, indicates that although in winter the total cooling loads were significantly increased in peak winter month while minor reductions were achieved in peak summer month. The increase in total cooling loads in winter offsets any reductions achieved by this façade configuration in summer. The annual total cooling load consumption is insignificantly less than the Base Case but more than the annual total cooling load demand for an un-insulated transparent double skin façade.

Case 3, indicates that changing the visual properties of glazing of the exterior leaf of the double skin façade leads to variable performance and significance in reducing total cooling loads whether in peak summer, peak winter and on annual levels.

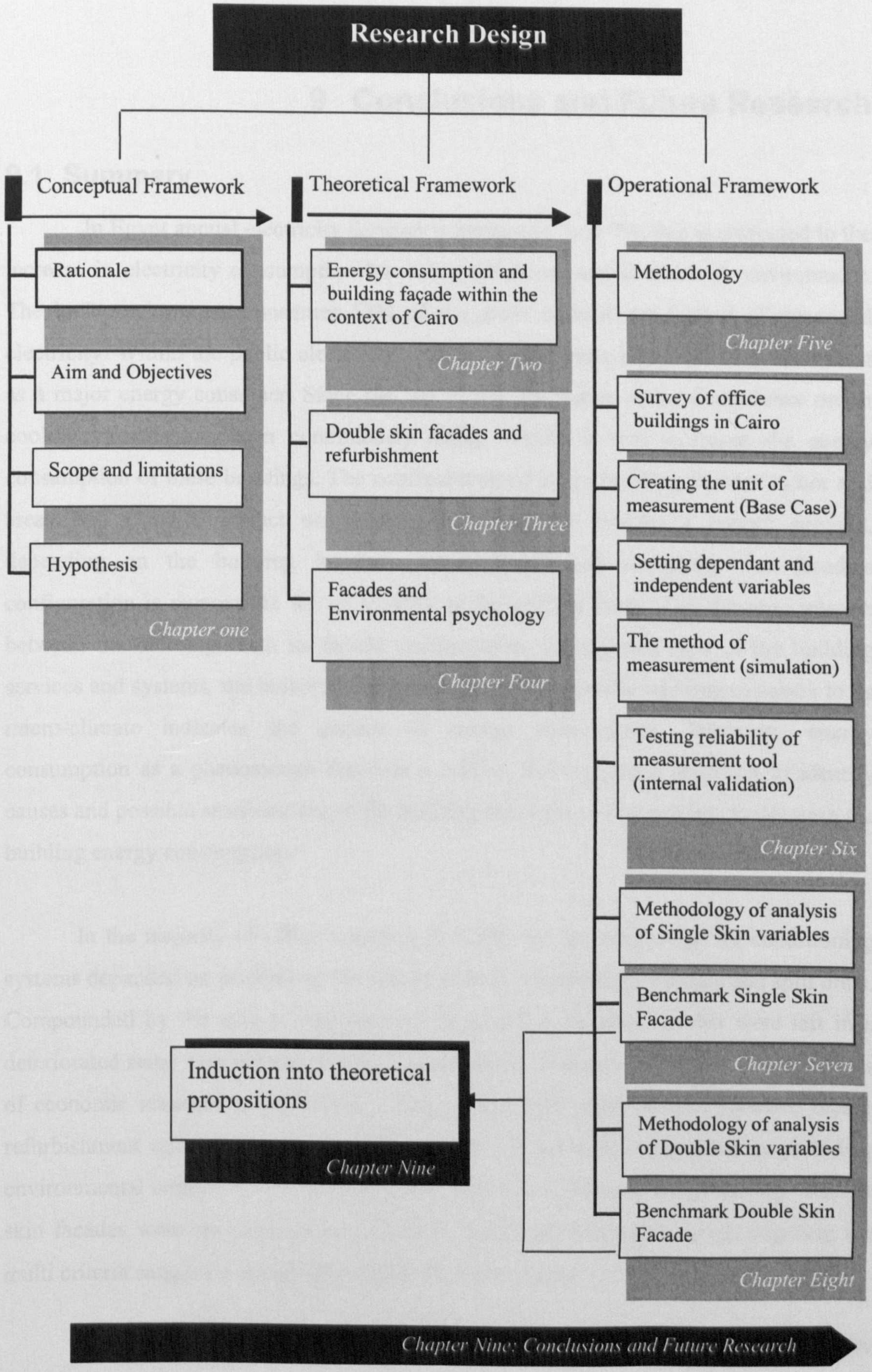
Case 4, indicates that if the outer leaf has reflective properties then significant reductions are achieved year round. This is attributed to preventing the penetration of direct solar radiation before it enters the cavity then indoors through inner glazing.

Case 5 looked into generalizing findings from Case 4 on various existing façade configurations by varying the Window to wall ratio on the inner leaf of the double skin façade. AS opposed to the effect from decreasing the Window to Wall ratio on the single skin façade decreasing on increasing the WWR on the inner leaf of the reflective double skin façade has an insignificant change on cooling loads. This indicates that a reflective double skin façade may give design and refurbishment freedom to connect to the exterior environment. Although conduction gains are expected to rise with the increase in inner WWR ratios, but this rise is insignificant on total cooling loads. The first line of defence to direct solar radiation by using a reflective double skin façade is effective.

The effect of using a benchmark Double Skin façade on providing day lighting levels appropriate for the workplace activities in office buildings was examined. The Base Case, and benchmark single skin were compared to the performance of Benchmark Double Skin in winter and summer in both direct and diffuse solar radiation hours. The Benchmark Double skin performed the best in providing a uniform day lit interior space during clear sky conditions whether in summer or in winter. However, in Winter the Benchmark Double Skin led to severe reductions in day lighting levels that may lead to the use of electrical lighting to provide a suitably illuminated interior for work on visual display screens. In winter during diffuse solar radiation hours, the Base Case with its clear glazing provided the best uniformly lit interior space.

The arguments on how to balance the need for day light and reducing cooling loads is contradictory and controversial. It is clear that in Winter, clear glazing is predicted to provide a uniformly lit interior but due to the short time of exposure to this condition in hot arid climates reducing the penetration of direct solar radiation takes precedence. In this case, both the Benchmark Double Skin and Benchmark Single Skin are viable options for Cairo from a day lighting perspective.

Chapter Nine: Conclusions and Future Research



Research Design
Conceptual Framework
Theoretical Framework
Operational Framework
Rationale
Aim and Objectives
Scope and limitations
Hypothesis
Chapter one
Energy consumption and building façade within the context of Cairo
Chapter Two
Double skin facades and refurbishment
Chapter Three
Facades and Environmental psychology
Chapter Four
Methodology
Chapter Five
Survey of office buildings in Cairo
Creating the unit of measurement (Base Case)
Setting dependant and independent variables
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Chapter Six
Methodology of analysis of Single Skin variables
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Methodology of analysis of Double Skin variables
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9 Conclusions and Future Research

9.1 Summary

In Egypt annual electricity demand is increasing by 6-7%, this is attributed to the increase in electricity consumption for industrialization, and in the built environment. The built environment consumes 52% of the gross national production of generated electricity. Within the public electricity consumption domain, office buildings stand out as a major energy consumer. Since the late 1970s, the public sector dependence on air cooling systems has been continuously rising, which in turn increases the energy consumption of these buildings. The configuration of office building facades in hot arid areas has a major impact on reducing/increasing the building's energy demand, depending on the building location, micro-climate and occupancy the façade's configuration is responsible for up to 40% of the cooling loads. The dynamic relation between the building -with its façade configuration, the age and type of the building services and systems, the building occupational patterns- and the building exposure to its micro-climate indicates the pattern of energy consumption. Therefore, energy consumption as a phenomenon deserves a holistic and integrated approach to identify causes and possible ameliorations to the building envelope and its systems to decrease the building energy consumption.

In the majority of office buildings in Cairo, the introduction of air conditioning systems depended on perforating the façade with air conditioning window and split units. Compounded by the lack of maintenance funds office building facades were left in a deteriorated state. This deterioration of image leads to abandonment of buildings and loss of economic revenue. In this context, there is a need to apply a least intrusive façade refurbishment option, to retain occupancy, and aid the building systems in providing environmental comfort to the building occupants with a reduced energy penalty. Double skin facades were investigated as a possible façade refurbishment option targeting the multi criteria sought for façade refurbishment in this thesis.

In the context of the thesis, reconciling energy conservation with a pragmatic sustainable attitude towards the refurbishment of office building facades in Cairo is seen as a viable progression towards the sustainability agenda. The literature review indicates that a pragmatic sustainable approach could not be undertaken effectively unless the whole building design teams utilize their expertise to produce commercially viable sustainable solutions. From the literature review it may be concluded that the way forward is by an intrinsic relationship between commercial reality, design ingenuity and innovations in using building materials and solutions to achieve a true commitment to quality low energy sustainable buildings.

Facades are complicated systems acting as modifiers to the ingress of stressors from the urban environment (noise and pollution) and climate indoor. In hot arid areas, traditionally the role of the fabric as an environmental moderator was facilitated by the integration of passive or hybrid systems (such as wind towers). However this study debates that although integration of building services within the building fabric was a vernacular stigma, there arises no need to adhere to old solutions to achieve façade thermal performance. Integrating new technologies maybe used to reinforce the building fabric as an environmental moderator and reduce buildings' reliance on generated energy to achieve indoor thermal comfort. Double skin facades are conceptualized as a multi layered environmental façade that may be used in building refurbishment.

Built on the previous context specific determinants, the scope of the thesis identifies energy consumption, façade technologies, refurbishment and environmental psychology as the major domains of related interest to the inquiry. The literature review provided no single theory or grand theory on the relation between these variables but rather singular approaches to identify the relation between two variables. A triangulated approach was adopted to combine these theories to capture a balance between applying façade technologies and improving environmental psychological aspects in the office workplace while reducing energy consumption in a hot aid context. To achieve the aim of the thesis different façade technologies were simulated to understand their thermal performance. Quantitative results of simulations were parametrically examined to identify benchmark options for façade refurbishment to reduce building cooling loads. Information generated from the simulation of single and double skin façade configurations were inducted into qualitative theories predicting human comfort aspects within the workplace. Three qualitative criteria underpinning the psychological comfort of occupants and its impact on productivity are set for balancing energy savings from the façade configuration with occupants' needs these are: the need for a view out, day light availability for non-task performances, and perceived control over the façade in work places.

The performance of double skin façade is predominantly carried out in moderate climates. Previous research indicated that the use of a clear double skin façade incorporating an automated shading system within its gap increased transparency of the building while reducing transmittance of direction solar radiation and propagation of noise. In the context of a hot arid climate and specifically in Cairo air pollution and sand storms are a major concern in the construction of façade configurations thus rendering automated façade shading devices uneconomic and in need of high maintenance standards and frequencies. This thesis studies the fundamental performance of applying double skin facades in a hot arid area while changing the optical properties of the external skin to reduce direct solar transmittance indoors. The study compared refurbishment scenarios for a single skin façade to achieve benchmark. The benchmark single skin façade is used to compare the performance of the double skin façade alternatives. Results indicated possible reductions to building cooling loads that varied according to the variations in the external glazing optical properties with reflective glazing offering the highest reductions in building cooling loads.

The use of double skin facades with a reflective surface is extended to study its daylight performance, availability of a view out and possibilities for occupants' control to balance the recommendations of this thesis.

9.2 Conclusions:

1. The original concept of office building facades design as an environmental moderator -combining using shading, natural ventilation and building mass- dominating office buildings in Cairo till late 1970 has changed, this is attributed to different environmental and urban stressors, political image transfer ideologies, building services and construction technology transfer, and adoption of the international working hours patterns from 9a.m.-5p.m.

2. Environmental stressors are related to an increase in traffic noise, industrial air pollution combined with dust storms and flying insects. As predicted by theories of environmental psychology (the overload theory, Environmental stress theory or behaviour constraint theory), if humans can not control, change or adapt to the environment, a sense of helplessness and lack of control emerges, which may lead to the occupants depending on building facades to separate them from these environmental stressors.

3. From a thermal performance perspective, using the façade as an environmental separator led to building up heat indoors and reduced natural ventilation as an opportunity to improve thermal comfort. Puncturing facades with air conditioning units was promoted as the solution to improve thermal comfort and increase productivity. This technological fix led in turn to increasing electricity demands.

4. From a psychological perspective, the failure of traditional shading systems to provide a psychological connector was pronounced. It is easily observed that occupants of these office buildings whenever possible removed the wooden shutters, left the clear glazing behind with no solar protection. These alterations alongside lack

of regular façade maintenance left the original office building façade in a deteriorated state and in desperate need for refurbishment.

5. The study of the context of Cairo revealed a challenging urban and environmental setting for locating office buildings. With its current ambient environmental profile, the increase in office operational energy demands and the current state of office building facades, it is concluded that to maintain indoor thermal and psychological comfort, integration between the building envelope physical characteristics and the air conditioning system design is required. Within these environmental constraints, façade refurbishment technologies were reviewed for a façade architectural technology with a potential to ameliorate collectively these environmental stresses on office building occupants with least disturbance to the building occupancy.

6. The conceptual framework of the thesis covered in chapter two looked at the function of the façade as not merely a separating layer between indoors and outdoor. In conclusion, the façade is not successful in delivering its multiple roles unless assessed as a holistic interface that not only acts as an environmental moderator with an impact on the buildings energy consumption, but has to meet predicted occupants expectations and psychological aspirations.

7. Chapter three reviewed architectural technologies used to enhance the integration between the façade thermal performance and the building systems in delivering occupants' comfort within a refurbishment framework. In conclusion, the availability and continuous improvement in glazing and insulation technologies offers an opportunity in reducing the building's operational energy. These technologies maybe used on a single skin façade or maybe extended to act in multiple layer facades that are capable of integrating passively or actively to reduce the operational energy. The following chapters looked in more details into these facade technologies within a refurbishment framework, in an attempt to parametrically analyze their effect on changing cooling loads.

8. Chapter four introduced the operational framework of the thesis and explained the research methodology. To examine the propositions intended in this study various test methods were discussed. A base case for simulation was configured based on knowledge gained from the literature review and an office building survey in Cairo. Simulation was chosen as a tool for quantitatively measuring the impact of changing façade variables on the total cooling loads of the building. A limited validation exercise using actual design and energy consumption data was utilized to validate simulation results used. Results indicated good agreement with those predicted by the software, indicating an acceptable level of internal validity and thus increasing confidence in the simulation software as a measurement tool.

9. Chapter five introduced the methodological model for testing variables affecting the single skin facades. A survey on current office building types in Cairo was carried out to identify the range of façade configurations in need of refurbishment. A scientific methodology is adopted to parametrically quantify energy saving measures predicted by simulating variables affecting the façade thermal performance to achieve a benchmark single skin configuration. In this context, hypotheses one to three are tested. Testing the base case indicated the need for cooling year round. Total cooling loads are a summation of sensible and latent loads. The effect of changing any façade variable as a refurbishment scenario is simulated to indicate changes in peak summer (maximum cooling load) and in peak winter (minimum cooling loads) and on annual basis.

9.1 Hypothesis one states that *'With no alterations to the architectural configurations (the proportions of glazed to opaque areas) of existing single skin facades, reducing conduction gains through the façade configuration will reduce the cooling and heating loads'*. Simulation results indicated the need for cooling year round. The reduction of conduction gains was tested by adding external insulation to the base case. Simulation results of the Base Case model indicated that the effect of conduction through the façade on the annual sensible cooling loads was minor 13% compared to the radiation gains 31% through the glazed areas. For opaque areas and glazed areas alike, reducing the U-value led to insignificant reductions in peak summer total cooling loads. This maybe attributed to the insulation preventing heat loss from the building fabric to the ambient during night time when air temperatures are lower than indoors. In winter, cooling loads were slightly increased as adding insulation decreased conductive losses, which leads to a cumulative increase in total cooling loads on annual basis. Therefore, reducing the opaque area's U-value by adding insulation, or reducing the transparent area's U-value by increasing glazing layers is not a recommended refurbishment option in the case of a completely sealed office building façade. However, using night time ventilation may lead to flushing out the trapped conduction gains, and then may indicated a better thermal performance of the insulted façade on total cooling loads. This was not tested in this thesis and remains to be considered in future research.

9.2 Hypothesis two states that *'With no alterations to the architectural configurations of existing single skin façade configurations, reducing radiation gains through the transparent façade areas will reduce cooling and heating loads.'* This was studies by varying the shading coefficient of glazing. Results indicated that for a constant Window to Wall Ratio (WWR) using reflective glazing was more efficient in reducing total cooling loads than tinted glazing. Thus confirming the rule of thumb on glazing alterations in refurbishment scenarios requiring solar transmittance control. Altering clear glazing on the Base Case model to reflective glazing produced the most significant reductions on total cooling loads in peak summer, peak winter and annually among variables tested on the single skin. Therefore this is considered a Benchmark Single Skin façade (BSS).

The previous hypothesis tested refurbishment variables that may be executed as minor refurbishment work to an existing façade. Hypothesis three stating that *'Major Alterations to the architectural façade configurations by reducing Window to Wall Ratios (WWR), and the Shading Coefficient (SC), will significantly decrease heating and cooling loads'*. Is used to study the generalizability of applying the Benchmark Single Skin façade (BSS) to other existing façade configurations. Results indicate that among the three variable WWR façade configurations tested. The Benchmark Single Skin façade reduced total cooling loads significantly whether in peak summer, peak winter and annually. Combining reducing the WWR and the reflective glazing produced the most reductions in total cooling loads than the Base Case; however, reducing the WWR is not recommended. It is predicted that occupants accustomed to certain levels of visual continuity within their offices may dislike its reduction by reducing the WWR of existing facades even on grounds of energy saving.

10. In chapter Six, the methodological model for testing single skin façade variables was modified to test variables predicted to affect the performance of double skin facades in hot arid areas to achieve a benchmark double skin façade. Previous research in moderate climates indicated that double skin facades appears as a façade technology capable of reducing system loads and attaining energy savings only if compared to poorly designed single skin buildings.

10.1 Hypothesis four stated that: *'In a hot arid climate, compared to Benchmark Single Skin façade, a transparent double skin façade may not achieve lower cooling load demands'*. The transparent double skin façade with its configuration led to increased cavity temperatures. Pervious literature indicated that the performance of the double skin façade as a thermal buffer maybe enhanced by using insulation on the interior façade's face facing the cavity.. Results indicated that similar to the single skin façade reducing the U-value indicated minor reductions of total cooling loads in peak summer but the increase in total cooling loads in the winter months offset the summer total cooling loads saving thus leading to a cumulative increase in annual total cooling loads. In conclusion using a transparent double skin (TDS) with no insulation is better in performance than the insulated double skin.

10.2 Simulation results indicated that in hot arid climates insignificant total cooling load reductions were achieved by using the transparent double skin façade when compared to a poorly performing single skin façade (Base Case Model). However, in refurbishing historical buildings it may be recommended (incurring an energy penalty) to preserve the appearance of the façade and protect it from the impact of air pollution in urban areas and weathering factors.

10.3 Comparing the simulation results, the benchmark single skin is superior in its ability to control radiation gains and reduce total cooling loads than the transparent double skin (TDS) façade on all façade orientations whether on peak summer, peak winter of annual total cooling loads. The annual total cooling loads using the benchmark single skin façade was 8% less than the total cooling load achieved by using the transparent skin façade on East, west and South Façade. The North façade indicated a 2% difference between using the Benchmark Single Skin and Transparent Double Skin which indicates the insensitivity of this façade orientation to the two refurbishment scenarios tested.

10.4 Hypothesis five stated that *'Using a double skin façade configuration in a hot arid context with the exterior skin acting as a selective solar radiation barrier will reduce heating and cooling loads more than the Benchmark Single Skin façade configuration.'* To test this hypothesis Body Tinted and Reflective Glazing were used on the exterior façade leaf. Results indicated that compared to the Base Case Model as well as the Benchmark Single Skin significant total cooling load reductions were predicted when a selective double skin façade is used.

10.5 The use of tinted glazing on the exterior leaf of the double skin façade model was superior to the Benchmark Single Skin in reducing the total cooling load on monthly levels year round. The annual total cooling load reductions are predicted to decrease 12% than the Benchmark Single Skin Façade. Compared to Base case (considered as a poor thermal performance façade) reductions of the annual total cooling loads were predicted to be 19% less.

10.6 The use of reflective glazing on the exterior leaf of the double skin façade model indicated the most reductions to total cooling loads among all façade variables tested on both the single and double skin façade models. Annual total cooling loads reductions are predicted to be 32% less than Benchmark Single Skin. Compared to the Base Case Model reductions on annual total cooling loads are predicted to be 40% less, which leads to major downsizing of the building air-conditioning systems, as well as significant cuts in electricity bills. Considering the benefits of using a reflective double skin façade it is considered as a Benchmark Double Skin (BDS) façade configuration.

10.7 To test the generalizability of the success of the BDS as a façade refurbishment scenario, it was tested on various WWR ratios ranging from a hypothetical opaque wall to a hypothetical completely glazed wall. Results indicated that using the Benchmark Double Skin Façade configuration allows for a freedom to enlarge WWR on the inner façade leaf without a significant energy penalty on all façade orientations. In this case changing the inner façade leaf configuration is considered a major refurbishment scenario as may incur the need to evacuate either the whole or sections of the building. In this case, using larger WWR on the inner leaf maybe a possible new built solution rather than a refurbishment option.

10.8 Comparing using the Benchmark single skin or the Benchmark Double Skin as a refurbishment option for existing office building façade configurations indicated the superiority of the BDS. The WWR on the interior leaf were varied between 20-40% corresponding to the façade configurations identified by the survey for office building in their refurbishment phase. Results indicated that for all existing façade configurations the BDS reduced total cooling loads significantly compared to BSS. Looking at the results cross-sectionally, as opposed to the BSS, the BDS had an insignificant difference on the annual total cooling loads when WWR were varied. To test the validity of this conclusion analysis were extended to studying the differences between the BDS, BSS and the Base Case on WWR between 0-80 %. Results for the East orientation were tested and in conclusion, the BDS is superior to both the BSS and the BC a façade technology allowing for freedom of design and reductions in total cooling loads year round.

11. Finally, the logical stream on concluding on optimum façade technologies for refurbishment based on minimum energy consumption may lead to de-value individual needs from a building façade. The benchmark single and double skin thermal performances are qualitatively discussed in relation to predicted human comfort aspects of the workplace. These environmental psychology aspects are the need for a view out, amenity lighting and occupants' perceived control over the façade in the workplace.

11.1 Simulations were carried out to predict the daylight availability indicated that the Benchmark Single Skin (BSS) provided more uniform indoor lighting levels than the base case. But during direct solar radiation hours high spots of illumination are seen nearer to the window areas, which may lead to drawing down curtains to avoid glare and perceived thermal discomfort. This in turn would lead to loss of visual continuity between indoors and outdoors. During direct sunshine hours and diffuse sunlight alike, the BDS indicated a more uniform distribution of daylight levels indoors. Even in winter, although the BDS reduced the day lighting levels significantly than the BSS, the predicted day lighting levels indoors under clear sky conditions are predicted to create a pleasant environment.

11.2 The literature review indicated that all exterior shading systems cause an increase in the air temperature in the air layers adjacent to the façade. The double skin façade is not an exception in this aspect. From a psychological perspective, as discussed in the literature review, occupants in hot arid areas do not tend to open windows if the outdoor environment is expected to be warmer than the inside. This attitude is useful in the case of using a double skin façade scenario. In summer, the cavity raised temperatures are beneficial to the buoyancy effect, but would only introduce warm air indoors if windows were opened during the working day. However, in winter and in-between seasons month the slightly elevated temperatures in the cavity (during diffuse radiation only) maybe used for natural ventilation as temperatures are found to be within the thermal comfort levels during the day. However, this aspect must be studied in detail to determine how it affects the buoyancy patterns and the air conditioning loads.

9.3 Future Research:

1. Further detailed studies on the interaction between the double skin facade configuration and occupants' perceived control are needed. However, if this aspect is indicated to cause psychological stress then maybe the Double skin façade configuration can be interrupted to include a benchmark single skin in parts of the façade.

2. The external generalizability of the performance of Double Skin facades in Cairo may be extended and verified by similar modelling and experimental testing in other cities in hot arid climates including various cities in the Middle East, USA and Australia.

3. Double skin facades also offer the opportunity to introduce night time ventilation while the building is secured by the outer leaf from excessive dust and theft. In moderate climates the integration between the air-conditioning systems and the façade were studied and few examples are built. The benefits of using return air from the cavity for air-conditioning systems needs further investigation within the climatic context of Cairo.

4. This thesis focused on studying the effect of changing the glazing thermal and visual properties on the cooling systems. The use of curtains is subjective and is not examined within the context of the thesis. Currently there are a number of commercially available perforated curtains and shading systems that may still provide

visual continuity and maybe used in the double skin façade's cavity. However, their use has to be examined in terms of how it affects the buoyancy effect on one hand, and on the other, day lighting levels and glare indoors.

5. Further studies based on integrating understanding of environmental, psychological, economical and integration between building services and the building shell aspects may then lead to optimizing the performance of the double skin façade configuration in a hot arid context. However, due to the varying functions, urban settings and design of a building, in practice these aspects have to be studied in integration for each building as a separate case.

6. Future research is needed to investigate the integrated performance of a double skin façade combined with renewable energy generators such as photovoltaics and solar cells for generating part of the building electricity demands in a hot arid context.

7. In Hot arid areas natural ventilation through opening windows is restricted during summer due to the prevailing climatic conditions. Due to the elevated cavity temperatures the utilization of double skin facades is expected to limit the possibility of natural ventilation during day time. However Future research on the possibility of using natural ventilation through the double skin façade configuration for night time cooling or for occupants in summer and autumn is an interesting aspect that needs further investigation.

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